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HUMAN PHYSIOLOGY.

EIGHTH EDITION. ENLARGED.

BRUBAKER.

? QUIZ-COMPENDS ? No. 4.

A

COMPEND

OF

HUMAN PHYSIOLOGY.

ESPECIALLY ADAPTED FOR THE USE OF
MEDICAL STUDENTS.

BY

ALBERT P. BRUBAKER, A.M., M.D.,

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PREFACE TO EIGHTH EDITION.

The preparation of an eighth edition of the Compend of Physiology has furnished the opportunity for a revision of a portion of the text and for the insertion of some fifteen pages of additional matter, both of which it is believed will materially enhance its value for medical and dental students during their attendance on the lectures and in reviewing the subject prior to examinations.

It is also believed that the chapters on the Physiologic Anatomy of the Skeleton and the Joints, the Physiology of Muscular Tissue and of Special Muscular Groups, will adapt it to the necessities of those Normal and High Schools in which it has already been in use.

Notwithstanding the many additions which have been made in this and previous editions, care has been taken to keep the Compend what it was originally intended to be, viz.: a compact and convenient arrangement of the fundamental facts of human physiology.

Again, my thanks are due to all those teachers who have kindly noticed and recommended the Compend to their students. That it may continue to merit the approval of both teachers and students is my earnest wish.

ALBERT P. BRUBAKER.

TABLE OF CONTENTS.

COMPEND

OF

HUMAN PHYSIOLOGY.

INTRODUCTION.

Definitions.—If the body of any animal be dissected it will be found to be composed of a number of well-defined structures, such as heart, lungs, stomach, brain, eye, etc., to which the term organ was originally applied, for the reason that they were supposed to be instruments capable of performing some important act or function in the general activities of the body. Though the term organ is usually employed to designate the larger and more familiar structures just mentioned, it is equally applicable to a large number of other structures which, though possibly less obvious, are equally important in maintaining the life of the individual, *e.g.*, bones, muscles, nerves, skin, teeth, glands, blood-vessels, etc. Indeed, any complexly organized structure capable of performing some function may be described as an organ. A description of the various organs which make up the body of an animal, their external form, their internal arrangement, their relations to each other, constitutes the science of ANIMAL ANATOMY.

This may naturally be divided into :—

1. *Special Anatomy*, the object of which is the investigation of the construction, form, and arrangement of the organs of any individual animal.
2. *Comparative Anatomy*, the object of which is a comparison of the organs of two or more animals, with a view of determining their points of resemblance or dissimilarity.

Human Anatomy is that department of anatomical science which has for its object the investigation of the construction of the human body.

An investigation of the vital phenomena exhibited by an animal, or of the

functions performed by its various organs, constitutes the science of ANIMAL PHYSIOLOGY.

This may naturally be divided into:—

1. *Special Physiology*, the object of which is a study of the vital phenomena or functions characteristic of any individual animal.
2. *Comparative Physiology*, the object of which is a comparison of the vital phenomena or functions exhibited by the organs of two or more animals, with a view of unfolding their points of resemblance or dissimilarity.

Human Physiology is that department of physiologic science which has for its object the study of the functions of the organs of the human body in a state of health.

GENERAL STRUCTURE OF THE ANIMAL BODY.

The body of every animal, from fish to man, may be divided into—

1. An axial, and
2. An appendicular portion. The axial portion consists of the head, neck, and trunk; the appendicular portion consists of the anterior and posterior limbs or extremities.

The Axial Portion of all mammals, to which class man zoologically belongs, as well as of all birds, reptiles, amphibians, and fish, is characterized by the presence of a bony, segmented axis, which extends in a longitudinal direction from before backward, and which is known as the vertebral column or backbone. In virtue of the existence of this column all the classes of animals just mentioned form one great division of the animal kingdom, *the Vertebrata.*

Each segment, or vertebra, of this axis consists of—

1. A solid portion known as the body or centrum, and
2. A bony arch arising from the dorsal aspect and surmounted by a spine-like process. At the anterior extremity of the body of the animal the vertebræ are variously modified and expanded, and with the addition of new elements form the skull. At the posterior extremity it rapidly diminishes in size and terminates in man in a short, tail-like process. In many animals, however, the column extends for a considerable distance beyond the trunk into the tail. The vertebral column may be regarded as the foundation element in the plan of organization of all the higher animals and the center around which the rest of the body is developed and arranged with a certain degree of conformity. In all vertebrate animals the bodies of the segment of the vertebral column form a partition which

serves to divide the trunk of the body into two cavities, viz., the dorsal and the ventral.

The dorsal cavity is found not only in the trunk, but also in the head. Its walls are formed partly by the arches which arise from the posterior or dorsal surface of the vertebræ and partly by the bones of the skull. If a longitudinal section be made through the center of the vertebral column, and including the head, the dorsal cavity will be observed running through its entire extent. Though for the most part it is quite narrow, at the anterior extremity it is enlarged and forms the cavity of the skull. Throughout this cavity is lined by a membranous canal, the neural canal, in which is contained the brain and the neural or spinal cord. Through openings in the sides of the dorsal cavity nerves pass out which connect the brain and spinal cord with all of the structures of the body.

The ventral cavity is confined mainly to the trunk of the body. Its walls are formed by muscles and skin, strengthened in most animals by bony arches, the ribs. Within the ventral cavity is contained a musculo-membranous tube or canal known as the alimentary or food canal, which begins at the mouth on the ventral side of the head, and after passing through the neck and trunk terminates at the posterior extremity of the trunk at the anus. It may be divided into mouth, pharynx, esophagus, stomach, small and large intestine.

In all mammals the ventral cavity is divided by a musculo-membranous partition into two smaller cavities, the thorax and abdomen. The former contains the lungs, heart, and its great blood-vessels, and the anterior part of the alimentary canal, the gullet or esophagus; the latter contains the continuation of the alimentary canal, that is, the stomach and intestines, and the glands in connection with it, the liver and pancreas. In the posterior portion of the abdominal cavity are found the kidneys and bladder, and in the female the organs of reproduction. The thoracic and abdominal cavities are each lined by a thin, serous membrane known, respectively, as the pleural and peritoneal membranes, which in addition are reflected over the surfaces of the organs contained within them. The alimentary canal and the various cavities connected with it are lined throughout by a mucous membrane. The surface of the body is covered by the skin. This is composed of an inner portion, the derma, and an outer portion, the epidermis. The former consists of fibers, blood-vessels, nerves, etc., the latter of layers of scales or cells. Imbedded within the skin are numbers of glands which exude, in the different classes of animals, sweat, oily matter, etc. Projecting from the surface of the skin are hairs, bristles, feathers, claws. Beneath the skin are found muscles, bones, blood-vessels, nerves, etc.

The Appendicular Portion of the body consists of two pairs of symmetric limbs which project from the sides of the trunk and which bear a determinate relation to the vertebral column. They consist fundamentally of bones surrounded by muscles, blood-vessels, nerves, and lymphatics. The limbs, though having a common plan of organization, are modified in form and adapted for prehension and locomotion, in accordance with the needs of the animal.

Anatomic Systems.—All the organs of the body which have certain peculiarities of structure in common are classified by anatomists into systems, *e. g.*, the bones, collectively, constitute the bony or osseous system; the muscles, the nerves, the skin, constitute, respectively, the muscular, the nervous, and tegumentary systems.

Physiologic Apparatuses.—More important from a physiologic point of view than a classification of organs based on similarities of structure, is the natural association of two or more organs acting together for the accomplishment of some definite object, and to which the term physiologic apparatus has been given. While in the community of organs, which together constitute the animal body, each one performs some definite function, and the harmonious cooperation of all necessary to the life of the individual, everywhere it is found that two or more organs, though performing totally distinct functions, are cooperating for the accomplishment of some larger or compound function in which their individual functions are blended, *e. g.*, the mouth, stomach, and intestines with the glands connected with them constitute the *digestive apparatus*, the object or function of which is the complete digestion of the food. The capillary blood-vessels and lymphatic vessels of the body, and especially those in relation to the villi of the small intestine, constitute the *absorptive apparatus*, the function of which is the introduction of new material into the blood. The heart and blood-vessels constitute the *circulatory apparatus*, the function of which is the distribution of blood to all portions of the body. The lungs and trachea, together with the diaphragm and the walls of the chest, constitute the *respiratory apparatus*, the function of which is the introduction of oxygen into the blood and the elimination from it of carbon dioxid and other injurious products. The kidneys, the ureter, and bladder constitute the *urinary apparatus*. The skin with its sweat-glands constitutes the *perspiratory apparatus*, the functions of both being the excretion of waste products from the body. The liver, the pancreas, the mammary glands, as well as other glands, each form a *secretory apparatus*, which elaborates some specific material necessary to the nutrition of the indi-

vidual. The functions of these different physiologic apparatuses, *e. g.*, digestion, the absorption of food, and the elaboration of blood, the circulation of blood, respiration, and the production of heat secretion and excretion, are classified as *nutritive functions*, and have for their final object the preservation of the individual.

The nerves and muscles constitute the *nervo-muscular apparatus*, the function of which is the production of motion. The eye, the ear, the nose, the tongue, and the skin with their related structures constitute, respectively, the *visual, auditory, olfactory, gustatory, and tactile apparatuses*, the function of which as a whole is the reception of impressions and the transmission of nerve impulses to the brain, where they give rise to visual, auditory, olfactory, gustatory, and tactile sensations.

The brain, in association with the sense organs, forms an apparatus related to mental processes. The larynx and its accessory organs, the lungs, trachea; respiratory muscles, the mouth and resonant cavities of the face form the *vocal* and *articulating apparatus*, by means of which voice and articulate speech are produced. The functions exhibited by the apparatuses just mentioned, viz., motion, sensation, language, mental and moral manifestations, are classified as *functions of relation*, as they serve to bring the individual into conscious relationship with the external world.

The ovaries and the testes are the essential reproductive organs, the former producing the germ-cell, the latter the spermatic element; together, with their related structures, the Fallopian tubes, uterus, and vagina in the female, and the urogenital canal in the male, they constitute the *reproductive apparatus* characteristic of the two sexes. Their cooperation results in the union of the germ-cell and spermatic element and the consequent development of a new being. The function of reproduction serves to perpetuate the species to which the individual belongs.

The animal body is therefore not a homogeneous organism, but one composed of a large number of widely dissimilar but related organs. But as all vertebrate animals have the same general plan of organization, there is a marked similarity both in form and structure among corresponding parts of different animals. Hence it is that in the study of human anatomy a knowledge of the form, construction, and arrangement of the organs in different types of animal life is essential to its correct interpretation; hence it is that in the investigation and comprehension of the complex problems of human physiology a knowledge of the functions of the organs as they manifest themselves in the different types of animal life is indispensable. As many of the functions of the human body are not only complex, but the organs exhibiting them are practically inaccessible to in-

vestigation, we must supplement our knowledge and judge of their functions by analogy, by attributing to them, within certain limits, the functions revealed by experimentation upon the corresponding but simpler organs of lower animals. This experimental knowledge, corrected by a study of the clinical phenomena of disease and the results of postmortem investigation, forms the basis of modern human physiology.

CHEMIC COMPOSITION OF THE HUMAN BODY.

Since it has been demonstrated that every exhibition of functional activity is associated with changes of structure, it has been apparent that not only is a knowledge of the chemic composition of the body when in a state of rest, but to a far greater degree when in a state of activity, necessary to a correct understanding of the intimate nature of physiologic processes. Though the analysis of the dead body is comparatively easy, the determination of the successive changes in composition of the living body is attended with many difficulties. The living material, the *protoplasm*, is not only complex and unstable in composition, but extremely sensitive to all physical and chemic influences. The methods, therefore, which are employed for analysis destroy its composition and vitality, and the products which are obtained are peculiar to dead rather than to living matter.

Chemic analysis, therefore, may be directed—

1. To the determination of the composition of the dead body.
2. To the determination of the successive changes which the living protoplasm undergoes during functional activity.

A chemic analysis of the dead body, with a view of disclosing the substances of which it is composed, their properties, their intimate structure, their relationship to each, constitutes what might be termed CHEMIC ANATOMY. An investigation of the living material and of the successive changes it undergoes in the performance of its functions constitute what has been termed CHEMIC PHYSIOLOGY or PHYSIOLOGIC CHEMISTRY.

By chemic analysis the animal body can be reduced to a number of liquid and solid compounds which belong to both the inorganic and organic worlds. The compounds resulting from a proximate analysis have been termed proximate principles. That they may merit this term, however, they must be obtained in the same form under which they exist in the living condition. The inorganic compounds consist of water and various

inorganic salts; the organic compounds consist of representatives of the carbohydrate, fatty, and proteid groups of organic bodies.

The proximate principles thus obtained can be further resolved by an ultimate analysis into a small number of chemic elements which are identical with elements found in many other inorganic as well as organic compounds. The different chemic elements which are thus obtained, and the percentage in which they exist in the body, are shown in the following table:—

ELEMENTARY COMPOSITION OF THE BODY.

Oxygen,	72.00	O. H. and C. are found in all the tissues and fluids of the body, without exception.
Hydrogen,	9.10	
Nitrogen,	2.50	O. H. C. and N. found in most of the fluids and all tissues except fat.
Carbon,	13.50	
Sulphur,	.147	In fibrin, casein, albumin, gelatin; as potassium sulphocyanid in saliva; as alkaline sulphate in urine and sweat.
Phosphorus,	1.15	In fibrin and albumin; in brain; as trisodium phosphate in blood and saliva, etc.
Calcium,	1.30	As calcium phosphate in lymph, chyle, blood, saliva, bones, and teeth.
Sodium,	.10	As sodium chlorid in all fluids and solids of the body, except enamel; as sodium sulphate and phosphate in blood and muscles.
Potassium,	.026	As potassium chlorid in muscles; generally found with sodium as sulphates and phosphates.
Magnesium,	.001	Generally in association with calcium, as phosphate, in bones.
Chlorin,	.085	In combination with sodium, potassium, and other bases, in all the fluids and solids.
Fluorin,	.08	As calcium fluorid in bones, teeth, and urine.
Iron,	.01	In blood-globules; as peroxid in muscles.
Silicon,	a trace	In blood, bones, and hair.
Manganesium,	a trace	Probably in hair, bones, and nails.

Of the four chief elements which together make up *97 per cent.* of the body, O. H. N. are eminently *mobile*, *elastic*, and possess great *atomic heat*. C. H. N. are distinguished for the narrow range and feebleness of their affinities and chemical inertia. C. has the greatest atomic cohesion. O. is noted for the number and intensity of its combinations and its remarkable display of chemic activity.

Chemic Elements, with the exception of the gases, O. H. and N., do not exist alone in the body, but are combined in characteristic propor-

tions to form compounds, the *proximate principles*, the ultimate compounds to which the fluids and solids can be reduced.

Proximate Principles may be divided into four classes, viz.: Inorganic, organic non-nitrogenized, organic nitrogenized, and principles of waste.

I. INORGANIC PROXIMATE PRINCIPLES.

Substance.	*Where found.*
Oxygen,	Lungs and blood.
Hydrogen,	Stomach and intestines.
Nitrogen,	Blood and intestines.
Carbonic anhydrid,	Expired air of lungs.
Carburetted hydrogen, Sulphuretted hydrogen,	Lungs and intestines.
Water,	Found in all solids and fluids.
Sodium chlorid,	In all fluids and solids except enamel.
Potassium chlorid,	In muscles, liver, saliva, gastric juice, etc.
Ammonium chlorid,	Gastric juice, saliva, tears, urine.
Calcium chlorid,	Bones, teeth, urine.
Calcium carbonate,	Bones, teeth, cartilage, internal ear, blood.
Calcium phosphate, Magnesium phosphate, Sodium phosphate, Potassium phosphate,	In all fluids and solids of the body.
Sodium sulphate, Potassium sulphate,	Universal except milk, bile, and gastric juice.
Sodium carbonate, Potassium carbonate,	Bones, blood, lymph, urine, etc.
Magnesium carbonate,	Blood and sebaceous matter.

Oxygen is one of the constituent elements of all the fluids and solids of the body. It is found in a free state in the respiratory passages and intestinal tract; it is held in solution in the lymph and plasma and forms a loose combination with the hemoglobin of the blood-corpuscles. The *function* of the oxygen in the body appears to be the oxidation of albuminous, oleaginous, and saccharine compounds to their ultimate forms, urea, carbonic acid, water, etc. As to whether this is brought about by direct oxidation or by a fermentative process is yet unknown. As oxygen only enters into combination under a high temperature, it is assumed that it exists in the body under the form of ozone, O_3, which possesses remarkably active oxidizing powers. The seat of oxidation is at present located in the tissues, as the presence of ozone in the blood has not been positively demonstrated.

Hydrogen is also a constituent element of almost all the compounds of the body; it exists in a free state in the intestinal tract, where it is produced by a decomposition of organic substances; it is also produced within the

tissues as a result of chemic changes. Its function is unknown, though it is asserted by Hoppe-Seyler that hydrogen unites with neutral oxygen, O_2, in the tissues, forming water and liberating oxygen in the nascent state, which becomes the oxidizing agent. The process is represented in the following equation:—

$$HH + O_2 + n = H_2O + On,$$

in which n represents the oxidizable substance.

Water is an essential constituent of all the tissues of the body, constituting about 70 per cent. of the entire body weight. It is introduced into the body in the form of drink and as a constituent of all kinds of food. The average quantity consumed daily is about four pints. While in the body, water acts as a general solvent, gives pliability to various tissues, and promotes the passage of inorganic and organic matters through animal membranes. It also promotes chemic changes which are essential to absorption and assimilation of food and the elimination of products of waste. It is probable that water is also formed within the body by the union of oxygen with the surplus hydrogen of the food. It is eliminated by the skin, lungs, and kidneys.

Sodium chlorid is present in all the solids and fluids of the body, with the exception of enamel. It regulates osmotic action, holds the albuminous principles of the blood in solution, and preserves the form and consistence of blood corpuscles and the cellular elements of the tissues by regulating the amount of water entering into their composition.

Calcium phosphate is the most abundant of all the inorganic principles with the exception of water, and is present to a great extent in bone, teeth, muscles, and milk. It gives the requisite consistency and solidity to the different tissues and organs. In the blood, it is held in solution by the albuminous constituents.

The *Sodium* and *Potassium phosphates* are present in most of the solids and fluids, and give to them their alkaline reaction. They are chiefly derived from the food.

II. ORGANIC NONNITROGENIZED PRINCIPLES.

The organic nonnitrogenized principles are derived mainly from the vegetable world, but are also produced within the animal body. They are divided into:—

1. The *carbohydrates*, comprising starch and sugar, bodies in which the oxygen and hydrogen exist in the proportion to form water, the amount of carbon being variable.

2. The *fats*, bodies having the same elements entering into their composition, but with the carbon and hydrogen increased and the oxygen diminished in amount.
3. Fatty acids.
4. Alcohols.

SUGARS. C. H. O.

Dextrose Group.	*Cane-Sugar Group.*
Dextrose (Glucose, grape sugar).	Saccharose (cane sugar).
Levulose.	Maltose.
Galactose.	Lactose.

The members of the dextrose group have a composition as follows: $C_6H_{12}O_6$, and are frequently spoken of as monosaccharids. The members of the cane-sugar group have a composition as follows: $C_{12}H_{22}O_{11}$, and are frequently spoken of as disaccharids.

Dextrose has been found in many of the tissues and fluids of the body as a normal constituent. As it is readily assimilable, it is probable that under this form the carbohydrates are absorbed into the blood. As its name implies, it rotates the plane of polarized light to the right.

Levulose is found in the stomach and intestine, and occasionally in the urine. It is formed by a decomposition of saccharose. While resembling dextrose in many respects, it differs from it in rotating the plane of polarized light to the left.

Galactose can be obtained from brain substance by the action of boiling sulphuric acid and by the decomposition of lactose. It is also dextrorotatory.

Saccharose is the form of sugar largely consumed as food. It is largely distributed throughout the vegetable kingdom in the juices of fruits and plants. It is not found, however, as a constituent of any of the fluids or solids of the body. During its passage through the stomach and intestine it is converted by the action of ferments into equal parts of dextrose and levulose by the assumption of a molecule of water. Cane sugar is, therefore, not absorbed under its own form, as it is nonassimilable, appearing in the urine after its injection into the blood.

Maltose is the final product formed by the action of saliva and a pancreatic juice on starch paste. It is also nonassimilable, and is, probably, converted into dextrose after or during absorption.

Lactose is the form of sugar naturally present in milk. It resembles the two preceding forms in being nonassimilable and nonfermentable.

Glycogen is the only form of starch found as a constituent of the animal tissues. It is closely related to the sugars.

The sugar of the body is derived from the food. After being converted into dextrose in the alimentary canal, it is absorbed into the blood by the veins of the portal system, and for the most part stored up in the liver under the form of glycogen. When the tissues require sugar for the performance of their normal activities, it is returned to the circulation and carried to all portions of the body. Whatever the intermediate stages may be, sugar is ultimately oxidized, contributing to the production of heat. It is eliminated under the forms of CO_2 and H_2O.

NEUTRAL FATS. C. O. H.

Palmitin.
Stearin.
Olein.

The *Neutral fats*, when combined in proper proportions, constitute a large part of the fatty tissue of the body; they are soluble in ether, chloroform, and hot alcohol; insoluble in cold alcohol and water, and liquefy at a high temperature. When a neutral fat is subjected to a high temperature in the presence of water and an alkali, it is decomposed, with the assimilation of the elements of water, into a fatty acid and glycerin. The fatty acid combines with the alkali and forms an oleate, palmitate, or stearate, according to the fat used. A similar decomposition of the neutral fats is said to take place in the small intestine during digestion. When thoroughly mixed with pancreatic juice, the fats are reduced to a condition of *emulsion*, a state in which the fat is minutely subdivided and the small globules held in suspension.

FATTY ACIDS. C. O. H.

Palmitic acid.	Propionic acid.
Stearic acid.	Butyric acid.
Oleic acid.	Caproic acid.

The *Fatty acids*, combined with sodium, potassium, and calcium, are found as salts in various fluids of the body, such as blood, chyle, feces, etc. Phosphorized fats in nervous tissue, butyric acid in milk, propionic acid in sweat, are also constituents of the body.

The Fats are derived from the food, both animal and vegetable. They are deposited in the form of small globules in the cells of the different tissues, are suspended in various fluids, are deposited in masses in and around various anatomic structures, and beneath the skin. Independent of the fat consumed as food, there is good experimental evidence that fat is also produced within the animal body from a partial decomposition of the albuminous compounds. Fat serves as a nonconductor of heat, gives roundness and

form to the body, and protects various structures from injury. The fats are ultimately oxidized, thus giving rise to heat and force, and are finally eliminated as carbonic acid and water.

ALCOHOLS.

Glycerin. Cholesterin. Alcohol.

Glycerin is chemically a triatomic alcohol in combination with the neutral fats of the body. During pancreatic digestion it is set free. It is supposed by many physiologists to be directly concerned in the production of glycogen. *Cholesterin* is a crystallizable substance largely present in the bile, though it is found in other fluids and solids. It is supposed to be a waste product of nervous matter. *Alcohol* has been found in the urine. It is supposed to be the result of an alcoholic fermentation in the intestine.

III. ORGANIC NITROGENIZED PRINCIPLES.

The *nitrogenized or proteid compounds* are organic in their origin, being derived from the animal and vegetable world; they are taken into the body as food, appropriated by the tissues, and constitute their organic basis; they differ from the nonnitrogenized substances in not being crystalline, but amorphous, in having a more complex but just as definite composition, and containing, in addition to C. O. H., nitrogen, with, at times, sulphur and phosphorus. The proteids possess characteristics which distinguish them from all other substances: viz., a *molecular mobility*, which permits *isomeric* modifications to take place with great facility; a *catalytic influence*, in virtue of which they promote, under favorable conditions, chemical changes in other substances; *e.g.*, during digestion, salivin and pepsin cause starch and albumin to be transformed into sugar and albuminose respectively. Different proteids possess varying proportions of water, which they lose when subjected to desiccation, becoming solid; but upon exposure to moisture they again absorb water, regarding their original condition,—they are *hygroscopic*. Another property is that of *coagulation*, which takes place under certain conditions; *e.g.*, the presence of mineral acids, heat, alcohol, etc.

After death the nitrogenized compounds undergo *putrefactive* changes, give rise to carburetted and sulphuretted hydrogen and other gases. In order that these changes may take place it is essential that certain conditions be present, viz.: *atmospheric air* or some fluid containing oxygen, *moisture*, and a *temperature* varying between 60° and 90° F. The cause of the putrefactive change is the presence of a minute unicellular organism, the *bacterium termo*.

The nitrogenized bodies found in the organism are quite numerous, and although they resemble each other in many particulars, there are yet important differences; they can be arranged into the following groups:—

1. NATIVE ALBUMINS.—Proteid bodies soluble in water, many acids, and usually in alkalies; coagulable at a temperature of from 140° to 163° F.
   a. *Serum Albumin*, the principal form of albumin found in the animal fluids and solids.
   b. *Egg Albumin*, not found in ordinary tissues, but present in white of egg.
2. GLOBULINS.—Proteid bodies insoluble in water, but soluble in solutions of sodium chlorid.
   a. *Globulin*, found in many tissues, but largely present in crystalline lens.
   b. *Myosin*, found in the muscles in life in a fluid condition; after death it undergoes coagulation, giving rise to the rigidity of the muscles.
   c. *Paraglobulin*, present in blood and obtained from it by passing a stream of carbon dioxid through it; it is also precipitated by adding sodium chlorid.
   d. *Fibrinogen*, present in serous fluid and blood, and can be precipitated by the prolonged use of carbon dioxid; it is also precipitated by the addition of 12 to 16 per cent. of sodium chlorid.
3. DERIVED ALBUMINS.—Proteid bodies which are not coagulable by heat; insoluble in pure water and in salt solutions; soluble in both acid and alkaline solutions.
   a. *Acid Albumin*, found principally in the stomach during first stage of digestion, the result of the action of the hydrochloric acid upon the albumin of the food.
   b. *Alkali Albumin*, found in the intestine during pancreatic digestion, the result of the action of alkalies upon the albumin of the food.
   c. *Casein*, the chief proteid of milk; it is precipitated by acetic acid and coagulated by rennet.
4. PEPTONES.—These bodies are formed in the stomach and intestinal tract by the action of the gastric and pancreatic juices upon the albumins of the food. They are very soluble in water, alkaline and acid solutions; noncoagulable by heat; very diffusible. They are precipitated by tannic acid and alcohol.
5. ALBUMINOIDS.—The albuminoids are the results of various modifications of albumins occurring during the nutritive process, as well as by the action of various external influences.

a. *Mucin*, the characteristic ingredient of mucus secreted by the mucous membranes, giving to it its viscidity.
b. *Chondrin*, found in cartilage.
c. *Gelatin*, found in connective tissue, tendons, ligaments, bones, etc.
d. *Elastin*, found in elastic tissue.
e. *Keratin*, found in skin and epidermic appendages, nails, hair, horn, etc.

6. FIBRIN.—A filamentous albumin obtained by washing blood-clots. It is insoluble in water and mineral acids.

As the properties of the compounds formed by the union of elements are the resultants of the properties of the elements themselves, it follows that the ternary substances, sugars, starches, and fats, possess a great inertia and a notable instability; while in the more complex albuminous compounds, in which sulphur and phosphorus are united to the four chief elements, molecular mobility, resulting in isomerism, exists in a high degree. As these compounds are unstable, of a greater molecular mobility, they are well fitted to take part in the composition of organic bodies, in which there is a continual movement of composition and decomposition.

IV. PRINCIPLES OF WASTE.

Urea,	Xanthin,	Sodium,	Urates.
Creatin,	Tyrosin,	Potassium,	
Creatinin,	Hippuric Acid,	Ammonium,	
Cholesterin,	Calcium Oxalate,	Calcium,	

These principles, which represent waste, are of organic origin, arising within the body as products of disassimilation or retrograde metamorphosis of the tissues; they are absorbed by the blood, carried to the various excretory organs, and by them eliminated from the body.

The excrementitious substances will be fully considered under excretion.

Proximate Quantity of the Chemical Elements and Proximate Principles of the Body, Weighing 154 lbs.

	lbs.	oz.		lbs.	oz.
Oxygen,	111	..	Water,	111	..
Hydrogen,	14	..	Albuminoids,	23	7
Nitrogen,	3	8	Fats,	12	..
Carbon,	21	..	Calcium phosphate,	5	13
Calcium,	2	..	Calcium carbonate,	1	..
Phosphorus,	1	12	Calcium fluorid,		3
Sodium, etc.,		12	Sodium sulphate, etc.,		9
	154	..		154	..

PHYSIOLOGY OF THE CELL.

The **Study of the Structure** of the body reveals that it is composed of a number of dissimilar parts, such as the brain, heart, lungs, muscles, etc., to which the name organ has been given. The organs upon a closer examination can be resolved into elementary structures, to which the name *tissue* has been given. The study of the physical and physiologic properties of the tissues has given rise to that department of anatomy known as HISTOLOGY, or, as it is largely prosecuted with the microscope, MICROSCOPIC ANATOMY. Notwithstanding the complexity of the body, the number of constituent tissues is not great. They can be classified as follows:—

1. *Epithelial.*
2. *Connective,* comprising the areolar, adipose, fibrous, elastic, cartilage, and bone.
3. *Muscular.*
4. *Nervous.*

The majority of the tissues, however, are not simple structures, but complexly organized masses, whose physiological properties are dependent upon and the resultant of the properties of the structural elements composing them.

Cells.—When the tissues are subjected to microscopic analysis, it is found that instead of being homogeneous they are complex structures composed of simpler elements to which the name cell has been given. The cell constitutes the primary, elementary, structural, or form element of all tissues, and may be said to consist of a minute mass of living matter. Every organized body takes its origin in a single cell, the ovum. However complex its structures may become, it can be shown by an ultimate analysis that they are composed of similar cells or of fibers, which are the products or modifications of cells. The cell may be defined, therefore, as the primary morphologic and physiologic unit of the organic world, to which every exhibition of life, whether normal or abnormal, is to be referred.

Structure of Cells.—Cells vary in their anatomic constitution in the different structures of the body and may be classed in three groups, viz.:—

1. Cells consisting of a *cell substance,* a *nucleus,* and one or more *nucleoli,* enclosed within a *cell membrane,* all these parts being found in the primitive ovum.
2. Cells consisting of a *cell substance* and a *nucleus* only; most of the cells of animal tissues have this structure. To this type of cell the name cytode has been given.

3. Cells consisting of the cell substance only.

Cells vary in size within considerable limits, from the size of a white blood cell, $\frac{1}{2500}$th of an inch, to that of the multipolar cells in the anterior horns of the gray matter of the spinal cord, $\frac{1}{200}$th of an inch, or to that of the ovum, the $\frac{1}{120}$th of an inch. They also differ considerably in shape, according to the locality in which they are found. When young and free to move in a fluid medium, they assume the spheric form; when subjected to pressure, they may assume cylindric, polygonal, fusiform, and stellate forms.

The Cell Substance consists of a soft, transparent, gelatinous, semifluid material, known as protoplasm or bioplasm. Though frequently homogeneous, it often exhibits a finely granular appearance. The characteristics of protoplasm, however, vary in different tissues and in different animals. While young cells consist almost entirely of protoplasm, mature cells contain, in addition, materials of an entirely different kind; *e. g.*, globules of fat, granules of glycogen, mucigen, pigment, digestive ferments, as pepsin, trypsin, etc., substances which are produced by the physiologic action of the protoplasm.

The chemic composition of living protoplasm is difficult of determination. When dead, it is found to be composed of water, proteid material, a small quantity of glycogen, fat, and inorganic salts.

When examined with the microscope, the cell substance or protoplasm exhibits a network, the *spongioplasm*, in the meshes of which is contained a transparent material, the *hyaloplasm*. The protoplasm of all cells possesses, in a varying degree, the property of irritability; that is, of reacting in a definite manner to some form of excitation. The response will vary according to the character of the element stimulated. If it be a muscular fiber, there will result a contraction; if it be a gland cell, a secretion. In some animal cells, as well as in many vegetable cells, currents are visible in the protoplasmic mass, which, in the absence of apparent external influences, are said to be spontaneous. Ameboid movements are observed in many animal cells, particularly when young. The irritability and other physiologic properties of protoplasm are dependent upon a due supply of nourishment and the maintenance of a normal temperature.

The Nucleus is an ovoid or spheric body embedded in the cell substance. It consists of a distinct membrane, enclosing a clear nuclear substance, which, however, is pervaded by an irregular network of fibers, which exhibit here and there enlargements, to which the term nucleoli is given. The meshes of this network contain a soft, interstitial substance.

The nuclear membrane and the fibers composing the network, staining readily with various dyes, are spoken of as *chromatin;* the interstitial substance, not staining, as *achromatin.*

The Cell Membrane is a very thin, transparent, homogeneous, and elastic structure, completely enclosing the cell substance. It varies in thickness and consistency in different tissues. It is permeable to water and aqueous solutions of various organic and inorganic substances. The cell membrane has no special physiologic activity, merely serving as a protective agent. It is a product of the cell substance.

MANIFESTATIONS OF CELL LIFE.

Growth and Assimilation.—All cells exhibit the three fundamental properties of life: growth, motion, and reproduction. Every living cell is, therefore, the seat of a series of chemic changes underlying the two phases of nutrition, assimilation and dissimilation. By the first process, the cell absorbs from its surroundings those materials necessary for its growth and physiologic activities. When newly reproduced, all cells are exceedingly small, but by the absorption of nutritive material and its subsequent assimilation and vitalization they gradually attain their mature size. Some of the absorbed material, instead of becoming an integral part of the protoplasm, is oxidized, giving rise to heat and force. As a result of cellular activity, there is also formed within the cell special substances, which, being finally eliminated, play some important part in nutrition. Coincident with the assimilative process, there are changes taking place of a disassimilative character; absorbed material, as well as tissue itself, is constantly being reduced to simpler forms, as carbon dioxid, urea, water, etc. The nutrition of the cell is, therefore, an epitome of the nutrition of the body as a whole.

Reproduction.—Like all organic structures, cells have a limited period of life; their continual decay and death necessitates a capability of reproduction. Cells reproduce themselves in the higher animals mainly by *fission.* This is seen in the white blood-corpuscles of the young embryos of animals; the corpuscle here consists of a cell substance and nucleus. When division of the cell is about to take place, the nucleus elongates, the cell substance assumes the oval form, a constriction occurs, which gradually deepens, until the original cell is completely divided and two new cells are formed, each of which soon grows to the size of the parent cell.

In cells provided with a cell membrane the process is somewhat differ-

ent. In the ova of the inferior animal, after fertilization has taken place, a furrow appears on the opposite sides of the cell substance, which deepens until the cell is divided into two equal halves, each containing a nucleus; this process is again repeated until there are four cells, then eight, and so on until the entire cell substance is divided into a mulberry mass of cells, completely occupying the interior of the cell membrane. The whole process of segmentation takes place with great rapidity, occupying not more than a few minutes, in all probability.

Motion.—In addition to the currents frequently observed in cell protoplasm, various other forms of movement have been observed; ameboid movements, the projection of pseudopodia, the waving of cilia, the activity of spermatozooids, the migration of blood-corpuscles, are among the different types of movement exhibited by many of the cells of the body.

By a combination of these primary structural elements, and of fibers and ground substances derived from or specially produced by them, all the tissues are formed which enter into the construction of the different organs of the body.

PHYSIOLOGY OF THE EPITHELIAL AND CONNECTIVE TISSUES.

Epithelial Tissue.—The epithelial tissue consists of one or more layers of cells resting upon a homogeneous membrane, the other side of which is abundantly supplied with blood-vessels. The form of the epithelial cell, varying in different situations, may be flattened, spheroid, or columnar, and is related to some special function. When arranged in layers, the cells are united by an intercellular substance. The epithelial tissue forms a continuous covering for the surfaces of the body. The external investment, the skin, as well as the mucous membrane which lines the entire alimentary canal and its associated body cavities, is formed in all situations by the basement membrane, covered with one or more layers of cells. All materials, therefore, whether nutritive or excretory, must pass through epithelial cells before they can enter into the formation of tissues or be eliminated from them. Chemically, epithelial cells are composed largely of keratin, a small proportion of water, and inorganic salts.

The consistency of epithelium varies in accordance with external influences, such as want of moisture, pressure, friction, etc. This is well seen in the skin and palms of the hands and soles of the feet, where it acquires

its greatest density. In the intestines, lungs, and other cavities, where the reverse conditions prevail, the epithelium is extremely soft. The epithelial tissues possess varying degrees of cohesion and elasticity, which enable them to resist considerable pressure and distention without having their integrity destroyed. Being bad conductors of heat, they assist in preventing rapid radiation from the body, and so maintain the normal temperature. The physiologic activity of all epithelial tissue depends upon a due supply of nutritive material furnished by the blood, which not only maintains its own nutrition, but affords material from which are formed the secretions of glands, whether of the skin or mucous membranes.

The functions of the epithelial tissues are:—

1. To serve as a protective covering to the underlying structures. Wherever there is repeated pressure, the epithelial cells become thick and indurated. Owing to their consistence they resist to some extent the injurious influences of acids and alkalies and various poisons.
2. As an absorbing agent. Inasmuch as the skin and mucous membrane cover the surfaces of the body, it is obvious that all nutritive substances entering the body must first traverse the epithelium. The epithelial cells covering the skin, owing to their density, play but a feeble rôle in man. The mucous membrane of the alimentary canal is the principal absorbing surface. The character of its epithelium permits of the absorption of water, peptones, sugars, salts. The epithelium lining the pulmonary air-vesicles is actively engaged in taking up oxygen and giving out carbon-dioxid.
3. As an eliminating agent. Waste products, however produced within the organism, must be taken up by the epithelium of the various excretory organs before being finally disposed of. The secretions of all glands are products of epithelial activity.

Connective Tissue.—The bony skeleton of the body is supplemented by a finer skeleton, composed of connective tissue, which pervades the entire body, and which, under various forms, serves as a bond of connection between its different parts, as a covering and protection for various organs, and as a basis of support for the elements of muscular, nervous, and glandular tissues.

The connective tissues include several varieties, among which may be mentioned areolar, adipose, fibrous, elastic, cartilaginous, and osseous. Notwithstanding their apparent diversity, they have many points of similarity. They have a common origin, developing from the same embryonic material; they have much the same structure, passing imperceptibly into

each other, and functionally perform the same office, viz., supporting and connecting the specific elements of the tissues or organs.

Areolar Tissue.—This variety is found widely distributed throughout the body in all situations. It serves to unite the skin and mucous membranes to the structures on which they rest, to unite and support blood-vessels, muscles, nerves, etc. When examined with the naked eye it presents the appearance of fine, transparent, colorless fibers, of delicate membranous lamina, which cross each other in every direction, leaving spaces or areolæ between them. Examined microscopically, these fibers are found to be composed of still finer white fibers cemented together by a transparent substance containing mucin. Other fibers are distinguishable by their straight course, their dark outline, their tendency to branch and to unite with adjoining fibers. When torn across they curl up at their extremities, owing to their property of elasticity. Distributed throughout the meshes of the areolar tissue are found flattened, irregularly branched or stellate corpuscles, the connective tissue corpuscles, plasma cells, and granule cells.

Adipose Tissue.—This exists very generally throughout the body, but is found most abundantly beneath the skin, around the kidneys, and in the bones. It is composed almost entirely of small vesicles more or less completely filled with fat-globules. The wall of the vesicle is protoplasmic, and contains at some points an oval, flattened nucleus. Adipose tissue can arise wherever connective tissue is found. It would appear that the granules of fat are produced by a transformation of the albuminous contents of the connective-tissue corpuscles. The vesicles are grouped together to form lobules, which in turn form irregular masses supported by connective tissue and blood-vessels.

Retiform Tissue.—This is also a variety of connective tissue made up very largely of white fibers interlacing in all directions. The spaces or areolæ are wanting in the usual ground substance, but are filled with fluid. Connective tissue corpuscles are abundant, but elastic fibers are absent. *Adenoid* tissue is but ordinary retiform tissue, the spaces of which, however, are filled with lymph corpuscles. It is found in lymphatic glands, in the central nervous system, and other situations.

Fibrous Tissue.—White fibrous tissue is exceedingly abundant and important. It forms the ligaments which hold the bones together, the tendons of the muscles, the membranes covering bones, cartilages, the septa of muscles, etc. Fibrous tissue is tough and strong but wholly inextensible, and, in consequence, is admirably adapted to fulfil various mechanical functions in the body. It is quite pliant, bending readily in any direction,

but difficult to break. When examined microscopically it is found to be composed of white fibers, resembling in all respects those of the areolar tissue. Treated with acetic acid they swell up and become indistinct. When boiled they yield gelatin, a derivative of collagen.

Elastic Tissue.—The elastic tissue is also an important member of the connective-tissue group. It is almost invariably associated with white fibers in some proportion, but in some tissues, as the ligamentum nuchæ, the ligamenta subflava, the coats of the large blood-vessels, it exists almost alone. In its pure state it presents a distinctly yellow appearance. The fibers of which it is composed are transparent, but present a distinct outline; they run almost parallel, but give off branches which unite to form a reticulated structure. As the name implies, these fibers are very extensible and elastic.

Cartilage is a modified form of connective tissue. It is opaque, bluish-white in color, though in thin sections translucent. In some situations it is firm in consistence, in others soft and elastic. All cartilage consists primarily of a ground or fundamental substance throughout which are scattered cells. There are two principal varieties in the human body, viz., hyalin and fibrocartilage.

Hyaline cartilage is the most typical form, the matrix of which being translucent and homogeneous. It is found on the ends of bones entering into the formation of joints, where it forms *articular* cartilage, between the ribs and sternum, forming the costal cartilages. It is also found in other situations. Microscopically examined, the ground substance reveals the presence of oval or spherical corpuscles containing one or more nuclei. The cell substance is frequently marked off from the ground substance by concentric lines, or fibers, which form a capsule for the cell. Repeated division of the cell substance frequently takes place, until the whole capsule is fully occupied with cells. The cell protoplasm is granular, and frequently contains drops of fat. According to some investigators the cell spaces are not isolated, but connected by fine channels, which in turn communicate with lymphatics. By these means nutritive fluid permeates the entire structure.

Fibrocartilage consists of two varieties, white and yellow.

White fibrocartilage consists of the usual ground substance pervaded by white fibers. It is firm and resistant, and found wherever strength and fixedness are required. Hence it is present between the vertebræ, forming the intervertebral discs, between the condyle of the lower jaw and glenoid fossa, in the knee-joint, around the margins of cup-shaped cavities, etc. In these situations it assists in maintaining the apposition of the bones, in giving a certain degree of motility to joints, and in diminishing the effect of

shock and pressure. The fibers of white cartilage are arranged in bundles and layers, the ground substances being relatively less abundant. Between the layers are the usual cartilage corpuscles.

Yellow fibrocartilage is found in the epiglottis, the external ear, Eustachian tube, and larynx. Primarily hyaline in character, the ground substance becomes pervaded with yellow fibers which branch and interlace in all directions, forming a dense network, but are so arranged as to form small spaces in which are found cartilage corpuscles surrounded by a soft matrix. These fibers are very elastic, and give to this form of cartilage a considerable degree of elasticity.

Osseous Tissue.—Osseous tissue, as distinguished from bone in the anatomic sense, belongs to the connective-tissue group, in which the fundamental substance is permeated with insoluble lime salts, the phosphate and carbonate being the most abundant. With dilute solutions of hydrochloric acid, these can be converted into soluble salts and dissolved out. The osseous matrix left behind is soft and pliable, and yields gelatin on boiling. The surfaces of all bones in the recent state, except where they are covered with cartilage, are invested with a fibrous membrane, the periosteum. The inner surface of this membrane is loose in texture, and supports a fine capillary plexus of blood-vessels and numerous protoplasmic cells, the "osteoblasts." As this layer is directly concerned in the formation of bone, it is spoken of as the *osteogenetic layer*.

A section of any bone shows that it is composed of two kinds of tissue, compact and cancellated. The compact resembles ivory, and is found on the outer surface; the cancellated is spongy, and to the naked eye appears to be made up of thin, bony plates, which intersect each other in all directions. It is found in great abundance in the interior of bones. The shaft of a long bone is hollow, the cavity extending almost from one extremity to the other. This central cavity, as well as the interstices of the cancellated tissue, is filled in the recent state with marrow. The *marrow* or *medulla* is a vascular tissue, the capillaries of which are supported by a delicate connective-tissue framework. In its meshes are to be found characteristic marrow cells, or osteoblasts, engaged in the formation of bone. The marrow in long bones is yellow, from the presence of fat resulting from a transformation of the protoplasm of connective-tissue cells. In the cancellated tissue, especially near the extremities, the fatty transformation does not take place, and the marrow remains red. The cells are supposed to give birth to red corpuscles.

Examined microscopically, a thin, transverse section of a bone reveals numerous small oval or round openings, which are the transverse sections

of canals which run, for the most part, in a longitudinal direction. These are the Haversian canals. In the living state, they are partly filled with blood-vessels and lymphatics. The canals are connected with each other and with the surfaces of the bones by numerous anastomosing branches. Around each Haversian canal is a series of concentric lamina, composed of fibers. Between every two laminæ are found small cavities (lacunæ) from which radiate in all directions small canals (canaliculi), which communicate freely with each other. The Haversian canals, with their associated lacunæ and canaliculi, form a series of intercommunicating passages, through which lymph passes for the nourishment of bone. In the cancellated tissue the blood-vessels pass through its interstices, and are supported by connective tissue. *Bone cells*, protoplasmic and nucleated, are found in each lacuna. When young, they are branched, sending their prolongations into the canaliculi.

Physical and Physiologic Properties of Connective Tissue.—Among the physical properties may be mentioned *consistency*, which varies from the semiliquid to the solid state. This variation depends upon the quantity of water in the individual tissues. Their *cohesion*, with the exception of the softer varieties, is considerable, and offers great resistance to traction, pressure, torsion, etc. In the various movements of the body, in the contraction of muscles, in supporting weights, in diminishing the effects of shocks, the properties of consistence and cohesion play important parts. Wherever the various forms of connective tissue are found, their chemic composition and structure are found to be in relation to their mechanical function. If traction be the preponderating force, the structures become fibrous, as in ligaments and tendons, and the cohesion greatest in the longitudinal direction. If pressure be exerted in all directions, as upon membranes, the fibers become interlaced and so offer an uniform resistance. When pressure is exerted in a definite direction, as upon the ends of long bones, the tissue assumes the cartilaginous form. *Elasticity* is also a property of all connective tissues, but is most marked in those containing an abundance of yellow elastic fibers. Elasticity plays an important rôle in many physiologic acts. It not only opposes and limits forces of traction, pressure, torsion, etc., but upon their cessation returns the tissues or structures to their original condition. It thus maintains the natural form and position of the organs by counterbalancing and opposing temporarily acting forces.

THE SKELETON.

Within the body of man and all vertebrated animals there is a highly developed framework, consisting of bones and cartilages, technically known as the skeleton (Fig. 1), the *function* of which is to afford support to all the softer tissues, to afford attachment for muscles, and to protect many delicate organs from injury. In addition to the bony skeleton there is a secondary framework, composed for the most part of fibrous or connective tissue, which ramifies everywhere throughout the body, uniting its various parts and affording support and protection to the ultimate elements of the tissues.

The skeleton naturally divides itself in accordance with the fundamental division of the body into—

1. An axial, and
2. An appendicular portion. The axial portion consists of the bones of the spine, the head, the ribs, and sternum; the appendicular portion consists of the bones of the extremities and the bony arches by which they are united to the trunk.

The Axial Skeleton.—The axial skeleton consists primarily of the spinal column, placed in the middle of the back of the neck and trunk, where it forms the foundation of the entire skeleton. It is composed of a series of superimposed bones termed *vertebræ;* above, it supports the skull; laterally it affords attachment for the ribs, which in turn support the weight of the upper extremities; below, it rests upon the pelvic bones, which transmit the weight of the body to the inferior extremities.

The Vertebral or Spinal Column consists in the child of 33 distinct bones, which are arranged in groups, named and numbered from their position, as follows: Cervical, 7; thoracic, 12; lumbar, 5; sacral, 5; coccygeal, 4, the latter being quite rudimentary. In the adult the sacral and coccygeal bones unite to form two separate composite bones, the sacrum and coccyx. Owing to their mobility the former are termed true, the latter false vertebræ. While the vertebræ of each group have certain characteristics in common, the type is best shown by the thoracic vertebræ.

The Thoracic Vertebræ present the following parts:—

1. A *body* or *centrum,* a short cylinder of bone slightly concave on its upper and lower surfaces, which is united to adjoining vertebræ by elastic discs of fibro-cartilage.
2. A *neural arch* consisting of two symmetrical halves each arising from the back of the body and uniting in the median line. Each arch con-

sists anteriorly of the *pedicle*, posteriorly of the *lamina*. At the point of union of the arches there is presented a prominent spine of bone which collectively give to the column its spiny character. From each side of the arch arises the *transverse* process, which projects outward and slightly backward. From the superior and inferior border of each lamina project the superior and inferior articulating processes.

The Cervical Vertebræ differ in some respects from the thoracic. The body is smaller, the neural arch larger, the spinous process shorter and often bifid. The transverse processes are broader and perforated by a foramen. The first and second vertebræ deviate markedly from the usual type. The first vertebra, or *atlas*, possesses neither a body nor a spinous process. It is practically a large neural ring provided with two lateral masses of bone which support the weight of the head. The second vertebra, or *axis*, has projecting from its body a vertical process, the odontoid process, around which the atlas bone rotates.

The Lumbar Vertebræ are the largest in the spinal column. The centrum gradually increases in width and strength from above downward, in accordance with the increasing weight of the body. The arches and processes are correspondingly enlarged.

The Sacrum is a triangular-shaped bone placed below the vertebræ. Its anterior surface is concave and presents four transverse ridges which mark the points of union of the primitive vertebræ and four openings on either side which communicate with the neural canal. The posterior surface is convex and marked by numerous partially developed processes which are homologous with the processes of the upper vertebræ.

The Coccyx is a rudimentary bone formed by the fusion of the bodies of four undeveloped vertebræ and terminates the spinal column.

The Spinal Column as a whole has an average length of about twenty-eight inches. Viewed laterally, it presents from above downward four curves. In the cervical and lumbar regions the curves are convex anteriorly, in the thoracic and sacral regions concave. These curves, taken in connection with the elastic intervertebral discs, impart to the spinal column considerable elasticity.

The Sternum is a thin, flat bone, situated in the median line in the anterior wall of the thorax. It consists of three segments, a superior, a middle, and an inferior, known respectively as the manubrium, the gladiolus, and the xiphoid appendix. The lateral borders of the sternum present

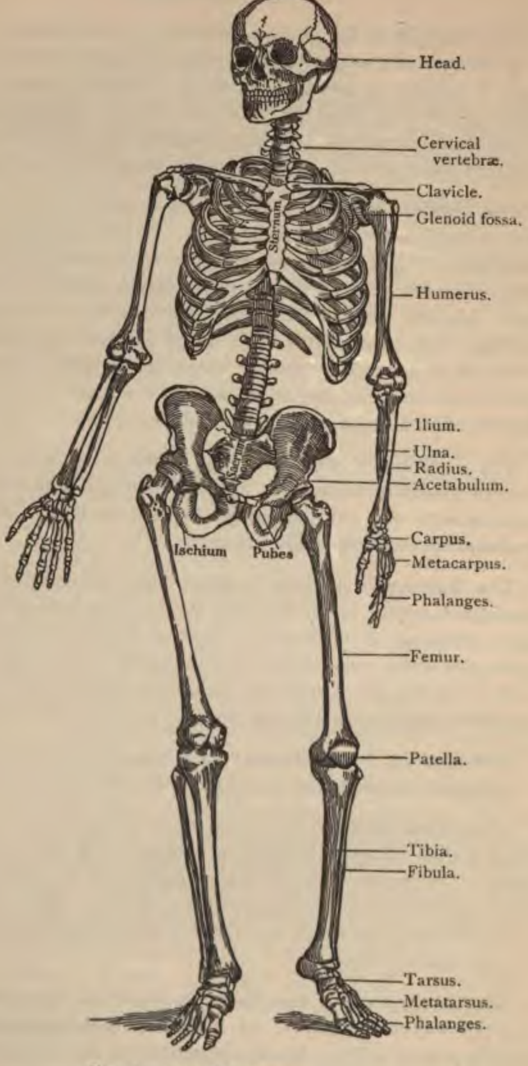

FIG. 1.—BONY SKELETON.

a series of depressions for the reception of the collar bone and the sternal ends of the cartilages of the first seven ribs.

The Ribs form a series of narrow, curved, flattened bones, attached posteriorly to the dorsal vertebræ, and continued anteriorly to the median line by the intermediation of cartilage. There are 24 ribs in number, 12 on each side. The first 7 are termed true ribs, from their attachment to the sternum; the remaining 5 are termed false ribs, of which the cartilages of the eighth, ninth, and tenth are attached to each other, while the eleventh and twelfth are free or floating. The ribs increase in length from the first to the seventh, and then decrease to the twelfth. Each rib consists of a beveled head for articulation with the dorsal vertebræ, a contricted portion, the neck, a tubercle for articulation with the transverse process, a curved shaft, compressed from side to side. Collectively the ribs form the lateral walls of the chest. The costal cartilages are the continuations of the ribs, and serve to connect them to the sternum.

The Thorax, as a whole, is a conical-shaped structure formed by the union of the thoracic vertebræ, the ribs, and sternum. It is compressed from before backward, so that the anteroposterior diameter is less than the transverse. The superior opening is oval in outline, measuring five inches from side to side, and two and one-half from before backward. The inferior opening is irregular, owing to the inclination of the ribs and the projection of the lower end of the sternum.

The Skull consists of 22 bones, of which 8 form the cranium, which encloses and protects the brain; the remaining 14 support the face and form the orbital, nasal, and mouth cavities. The cranial bones are:—

1. The *frontal bone*, which forms the forehead and roof of the orbits.
2. A pair of *parietal bones*, which form the sides and roof of the cranium.
3. The *occipital bone*, which forms the back of the head and part of the base. It is perforated by a large opening, the foramen magnum, through which the spinal cord passes. On either side of the foramen there is a large condyle, which articulates with the lateral masses of the atlas.
4. A pair of *temporal bones*, which aid in forming the sides and base of the skull and lodge the auditory organ.
5. The *sphenoid bone*, an irregular-shaped bone, situated at the base of the skull, where it forms a keystone for the cranial arch.
6. The *ethmoid bone*, situated between the skull and nasal chambers, and giving support to the olfactory organs.

The facial bones are paired, two only being single. The paired bones are:—

1. The *superior maxillæ*, or upper jawbones, situated one on either side of the middle line, assisting in the formation of the orbit, nose, and roof of the mouth. They also carry the upper teeth.
2. The *palatal bones* complete the hard palate and assist in forming the posterior nares.
3. The *nasal bones*, forming the bridge of the nose.
4. The *lacrimal bones*, lying between the orbit and nose.
5. The *malar bones*, lying beneath and to the outside of the orbit.
6. The *inferior turbinated bones*, one in each nasal chamber.
7. The *inferior maxilla*, or lower jawbone, is connected with the temporal bone on each side of the head. It carries the lower teeth and assists in mastication.
8. The *vomer* forms a portion of the partition of the nose.

THE APPENDICULAR SKELETON.

The appendicular skeleton consists of:—

1. The bones of the shoulder girdle and the bones of the arm, forearm, and hand.
2. The bones of the pelvic girdle and the bones of the thigh, leg, and foot.

The Shoulder Girdle is an imperfect bony arch connecting the limb directly with the axial skeleton. It consists of two bones, the clavicle and scapula.

The *clavicle* is a cylindrical bone extending from the upper end of the sternum upward and outward to be attached to the acromion process of the scapula.

The *scapula* is a flat triangular bone situated on the upper and back part of the thorax. It is not directly connected with the axial skeleton, being separated from it by a layer of muscle in which it is partly embedded. The posterior surface is divided by a spine of bone into two unequal portions. This spine gradually becomes more prominent as it passes from within outward; toward its termination it curves forward and forms the acromion process with which the clavicle articulates. The upper part of the outer edge of the scapula presents a slightly concave surface, pyriform in shape, which receives the upper extremity of the arm bone, known as the glenoid fossa. Overhanging this fossa is a strong bony process—the coracoid.

The skeleton of the arm and hand consists of 30 bones, the largest of

which, the *humerus*, lies in the arm. The *ulna* and *radius* are placed side by side in the forearm, and are so arranged that the radius can move to some extent around the ulna. The wrist or *carpus* contains 8 small bones, the *metacarpus* contains 5 long, cylindrical bones, the fingers 3, and the thumb 2.

The Pelvic Girdle, which forms the bond of union between the leg and the axial skeleton, consists of a single bone, the *os innominatum*, on each side, which articulates with the sacrum posteriorly; arching forward, it meets with its fellow of the opposite side in the median line, thus forming the lateral and anterior walls of the pelvic cavity. In the young child, this bone consists of three distinct bones, the ilium, ischium, and pubis, which, in adult life, fuse together to form the single bone. At the point of union on the external surface there is formed a large cavity, the *acetabulum*, which lodges the head of the thigh bone.

The skeleton of the leg and foot consists of 30 bones. The thigh bone, or *femur*, is the largest bone in the body, extending from the pelvic girdle to the knee. It is provided above with a rounded head, which fits into the acetabulum. This is connected with the shaft by a short neck, which forms with the latter an angle of 125 degrees. The lower extremity of the femur is enlarged to rest upon the bones of the leg. The leg bones are 2 in number, the *tibia* and *fibula*, the latter being placed external. In front of the knee is the *patella*. The *tarsus* consists of 7 bones, one of which, the *astragalus*, is united to the tibia and fibula to form the ankle. The *calcaneum* forms the heel. The *metatarsus* consists of 5 bones, each carrying a toe. There are 14 bones in the toes, 3 in each, except the large toe, which has but 2.

STRUCTURE AND MECHANISM OF JOINTS.

The various bones comprising the skeleton do not form a rigid framework, but are united by a variety of structures and in such a manner as to admit of varying degrees of movement. The points of union are termed *articulations*, or *joints*.

The structures entering into the formation of joints are:—

1. *Bones*, the articulating surfaces of which are often expanded and variously modified, as in the case of long bones.
2. *Hyaline cartilage*, which covers the articulating surfaces. Owing to its smoothness it facilitates the gliding movements of opposed surfaces, and by its elasticity diminishes the force of jars and shocks imparted to the

bones. White *fibrocartilage* in the form of interarticular discs is found in many joints. Placed between the ends of bones it subdivides the articulation and adjusts dissimilar surfaces.

3. A *synovial membrane*, consisting of connective tissue mixed with elastic tissue. Its inner surface is lined with endothelium, which secretes the synovial fluid, a colorless, viscid, alkaline fluid containing much mucin, albumin, and fat. Its *function* is to lubricate the articular surfaces and diminish friction.
4. *Ligaments*, tough bands of white fibrous tissue which pass from bone to bone in various directions. White fibrous tissue, being inextensible but pliant, maintains the bones in apposition and prevents displacement, but permits of easy movement within certain limits.

Modes of Articulation.—All articulations are divided, according to the extent of movement, into—

1. *Synarthrodial*, comprising those joints endowed with little or no motion; *e. g.*, joints or sutures uniting the bones of the skull.
2. *Amphiarthrodial*, comprising those joints endowed with a slight degree of mobility in consequence of an intervening plate of fibrocartilage and tough, unyielding ligaments; *e. g.*, vertebral and pelvic joints.
3. *Diarthrodial*, comprising those joints which are freely movable, the extent of movement, however, being variable. In all such joints the articulating surfaces are generally adapted to each other, are covered with smooth cartilage, lubricated with synovial fluid, and surrounded by ligaments which, while not preventing, yet limit the extent of movement. The diarthrodial joints may be divided according to the character of the movement into—
   a. Arthrodial, or gliding joints.
   b. Ginglymus, or hinge joints.
   c. Enarthrodial, or ball and socket joints.
   d. Trachoidal, or rotary joints.

The articulations may also be grouped in accordance with the fundamental divisions of the skeleton into—

1. Axial.
2. Appendicular.

THE AXIAL ARTICULATIONS.

The axial articulations are quite numerous and may be grouped into those uniting:—

1. The bodies of the vertebræ, the intervertebral joints.

2. The vertebræ with the ribs, the costovertebral joints.
3. The ribs with the sternum, the costosternal joints.
4. The vertebral column with the head, the occipito-atlantal joints.

The Intervertebral Joints are amphiarthrodial in character. The bodies of the vertebræ are united by tough, elastic discs of fibrocartilage which collectively constitute about one-quarter of the length of the vertebral column. The vertebræ are bound together by ligamentous bands situated on the anterior and posterior surfaces of their bodies and by short, elastic bands between the neural arches and processes. These structures combine to render the vertebral column elastic and flexible, and to enable it to resist and diminish the force of shocks communicated to it.

The function of the intervertebral joints and associated structures is not only to impart to the vertebral column the physical properties just mentioned, but to endow it with certain forms of movement necessary to the performance of various bodily activities. While the extent of movement between any two vertebræ is slight, the sum total of movement of all the vertebræ is considerable. Again, the extent of movement varies in different regions of the column, being limited and dependent upon the character of the vertebræ and the inclination of their articular processes. In the cervical and lumbar regions the movements of extension and flexion are freely allowed, extension being greater in the former, flexion being greater in the latter, particularly between the fourth and fifth vertebræ. Lateral flexion takes place in all portions of the column, but is particularly marked in the cervical region. A rotatory movement of the column as a whole takes place through an angle of 28 degrees. This is most marked in the lower cervical and dorsal regions. In the dorsal region the surfaces of the articular processes lie in the arc of a circle, the center of which is in front of the vertebræ, and in consequence permit of considerable rotation. In the lumbar region the reverse condition obtains and rotation is almost impossible.

The Costovertebral and Costosternal joints are diarthrodial in character. The former are formed by the apposition of the heads of the ribs with the dorsal vertebræ and the rib tubercles with the transverse processes, the latter by the anterior extremities of the ribs and sternum through the intermediation of the costal cartilages. Both sets of joints are provided with ligaments and closed synovial sacs.

The function of the costovertebral joints is to permit of an elevation and depression of the ribs coincident with a forward and backward gliding movement, which is essential to changes in the diameters of the thoracic cavity during respiration. At the costosternal joints the movements are

complex, the resultant, however, being an elevation of the anterior extremities of the ribs and an advance of the sternum during inspiration. During expiration the reverse takes place. The resultant of a combination of all the movements permitted at these joints is an elevation of the thorax, an advance of the sternum, and in consequence an increase in the transverse and anteroposterior diameters during an inspiratory movement. The reverse of these movements takes place during an expiratory movement.

The Occipito-atlantal joints are formed by the apposition of the superior concave surfaces of the lateral masses of the atlas and the convex surfaces of the occipital condyles.

The Atlanto-axoidean joints are formed laterally by the articular processes, centrally by the odontoid process, the anterior arch of the atlas, and the transverse ligament.

The function of these joints is to give to the head great variety and range in its movements. In flexion and extension, the movement takes place around a transverse axis, the occipital condyles gliding alternately backward and forward upon the lateral masses of the atlas. The rotation of the head is accomplished by a movement of the collar formed by the atlas and the transverse ligament around the odontoid process of the axis, which is so extensive as to permit of a range of vision through 180 degrees.

THE APPENDICULAR ARTICULATIONS.

The appendicular articulations comprise all those entering into the formation of—

1. The shoulder girdle, arm, and hand.
2. The pelvic girdle, leg, and foot.

The Shoulder Girdle presents two articulations. The *sternoclavicular*, which unites the clavicle to the sternum, and the *acromioclavicular*.

The function of these joints is to endow the shoulder girdle with considerable mobility—enabling it to execute a series of movements upon the thorax.

The Shoulder Joint, formed by the union of the hemispheric head of the humerus and the glenoid fossa of the scapula, belongs to the enarthrodial, or ball and socket, variety. Though surrounded by ligaments and a synovial membrane, the bones are retained in position largely by atmospheric pressure and muscular action.

The function of this joint is to endow the arm with great freedom of movement. Being a typical enarthrodial joint, the movements can take place in all directions; and consist of flexion; extension; abduction, which, at an angle of 90 degrees, is checked by the locking of the great tuberosity of the humerus with the acromion process of the scapula; adduction; circumduction, in which the arm describes a cone the apex of which is in the joint, the base at the distal extremity; rotation, in which the humerus revolves outward or inward around a vertical axis drawn through its head.

The Elbow Joint is formed by the union of the lower end of the humerus with the sigmoid cavity of the ulna and the cup-shaped depression on the head of the radius. Owing to the configuration of these bones, great security is afforded this joint, independent of its ligamentous attachment.

The function of this joint is to permit movements of flexion and extension only, the former being limited at an angle of 30 to 40 degrees by the contact of the coronoid process with the humerus, the latter by the contact of the olecranous process with the humerus, when the ulna is in a straight line. This joint is not, strictly speaking, a true ginglymus joint, inasmuch as flexion and extension are attended by a screw like movement as the ulna glides over the obliquely disposed articular surface of the humerus.

The Superior Radio-ulnar Joint is formed by the lesser sigmoid cavity of the ulna and the vertical border of the head of the radius, the latter being held firmly in position by the orbicular ligament.

The Inferior Radio-ulnar Joint is formed by the concavity on the inner aspect of the radius and the inferior extremity of the ulna.

The function of these joints is to permit movements of pronation and supination of the hand. The disposition of the ligaments at both articulations allows the head of the radius to revolve around a vertical axis and the inferior extremity to revolve around the ulna. In both supination and pronation the radius carries the hand with it.

The Radio-carpal, or Wrist Joint, is formed by the union of the inferior quadrilateral surface of the radius, the triangular fibrocartilage and convex surfaces of the carpal bones, the scaphoid, semilunar, and cuneiform.

The Carpal, Metacarpal, and Phalangeal Joints are formed by the union of the bones entering into the formation of the skeleton of the hand.

The function of these joints is to endow the hand with all varieties and combinations of movements, enabling it to perform a large number of delicate and complicated actions.

The Pelvic Girdle presents anteriorly the *interpubic joint* and posteriorly the *sacro iliac joints.*

The function of these joints, which are amphiarthrodial in character, is not so much to permit of movement, which is slight, as to prevent the forward and downward displacement of the sacrum and to enable it to transmit the weight of the body through the pelvic girdle to the lower extremities.

The Hip Joint is formed by the acetabulum on the outer surface of the os innominatum and the globular head of the femur, both structures being accurately adapted to each other. To retain the femur in position the acetabulum is deepened by a rim of cartilage; to render the joint more stable and to limit the extent of motion it is provided with strong ligaments and strengthened by overlying muscles.

The function of the hip joint is to permit all those movements of the trunk on the femur, or the reverse, which are involved in walking, running, rowing, and allied muscular acts. Being a typical enarthrodial joint, movements can take place in all directions within certain limits, and may be grouped as follows:—

1. A pendulum-like movement in any plane.
2. Rotation around the long axis of the limb.
3. Circumduction, in which the limb describes a cone, the apex of which is in the joint, the sides being formed by the limb itself.

The Knee Joint is formed by the apposition of the articular surfaces of the femur, tibia, and patella. It is partially subdivided by the interposition of two fibrocartilages. From the mechanical construction of this articulation displacement of the bones would readily take place were it not provided, as it is, with a large number of ligaments, tendons, and synovial membranes, which are so arranged as to make it the most complicated joint in the body.

The function of the knee joint, being ginglymus in structure, is to permit movements of flexion and extension, which cover an angle of about 145 degrees. These simple movements, however, are complicated by a gliding of the condyles upon the tibial facets so that the points of contact are constantly shifting. Owing to the shape of the condyles, extension is accompanied by outward rotation and flexion by inward rotation.

The Ankle Joint unites the skeleton of the foot to the lower extremity of the leg, and is formed by the apposition of the convex surface of the astragalus and the concavity of the tibia, and embraced on either side by the external and internal malleoli.

The function of the ankle joint is to permit of flexion and extension around an axis passing through the body of the astragalus, but at such an angle that the movements do not take place in a direct anteroposterior plane, but in a plane directed outward and forward. It serves to transmit the weight of the body to the foot.

The Tarsal, Metatarsal, and Phalangeal Joints unite the bones of the foot. They are very numerous and abundantly supplied with ligaments and synovial membranes.

The function of these joints is to endow the arches of the foot with considerable elasticity, to diminish the effects of jars or shocks that are transmitted to the vertebral column, and to adapt the foot to changes of form necessitated by the acts of walking, jumping, etc.

GENERAL PHYSIOLOGY OF MUSCULAR TISSUE.

The Muscular Tissue, which closely invests the bones of the body, and which is familiar to all as the flesh of animals, is the immediate cause of the active movements of the body. This tissue is grouped in masses of varying size and shape, which are technically known as muscles. Muscles are so arranged and connected, for the most part with the bones, in such a manner, that by an alteration in their form they can change not only the position of the bones with reference to one another, but can also change the individual's relation to surrounding objects. They are, therefore, the active organs of both motion and locomotion, in contradistinction to the bones and joints, which are but passive agents in the performance of the corresponding movements. In addition to the muscular masses which are attached to the skeleton, there are also other collections of muscular tissue surrounding cavities such as the stomach, intestine, blood-vessels, etc., which impart to their walls motility, and so influence the passage of material through them.

Muscles produce movement of the structures to which ey are attached by the property with which they are endowed of changing their shape,

shortening or *contracting* under the influence of a stimulus transmitted to them from the nervous system. Muscles are, therefore, divided into:—

1. *Voluntary muscles*, comprising those whose activity is called forth by stimuli of the nerves as the result of an act or effort of volition.
2. *Involuntary muscles*, comprising those whose activity is entirely independent of the volition.

The voluntary muscles are also known from their attachment to the skeleton as *skeletal*, and from their microscopic appearance as *striped* muscles. The involuntary muscles, from their relation to the viscera of the body, are known also as *visceral*, and from their microscopic appearance as plain or smooth muscles.

General Structure of Muscles.—All skeletal muscles consist of a central fleshy portion, the body or belly, which is provided at either extremity with a tendon in the form of a cord or membrane by which it is attached to the bones. The belly is the contractile region, the source of the motor activity; the tendon is an inactive region and merely transmits the movement to the bones.

A skeletal muscle is a complex organ consisting of muscular fibers, connective tissue, blood-vessels, and lymphatics. The general body of the muscle is surrounded by a dense layer of connective tissue, the *epimysium*, which blends with and partly forms the tendon; from its inner surface septæ of connective tissue pass inward and group the muscular fibers into larger and smaller bundles, termed *fasciculi*. The fasciculi invested by this special sheath, the *perimysium*, are irregular in shape, and vary considerably in size. The fibers of the fasciculi are separated from each other and supported by a delicate connective tissue, the *endomysium*. The connective tissue thus surrounding and penetrating the muscle binds its fibers into a distinct organ, and affords support to blood-vessels, nerves, and lymphatics. The muscular fibers are arranged parallel to each other, and their direction is that of the long axis of the muscle. In length they vary from 30 to 40 millimeters, and in diameter from 20 to 30 micromillimeters.

The Vascular Supply to the muscles is very great and the disposition of the capillary vessels with reference to the muscular fiber is very characteristic. The arterial vessels, after entering the muscle, are supported by the perimysium; in this situation they give off short, transverse branches, which immediately break up into a capillary network of rectangular shape within which the muscular fibers are contained. The muscular fiber in intimate relation with the capillary is bathed with lymph derived from it. Its contractile substance, however, is separated from the lymph by its own invest-

ing membrane, through which all interchange of nutritive and waste materials must take place. Lymphatics are present in muscle, but confined to the connective tissue, in the spaces of which they take their origin.

The Nerves which carry the stimuli to a muscle enter near its geometric center. Many of the fibers pass directly to the muscular fibers with which they are connected; others are distributed to blood-vessels. Every muscular fiber is supplied with a special nerve-fiber except in those instances where the nerve trunks entering a muscle do not contain as many fibers as the muscle. In such cases the nerve fibers divide until the number of branches equals the number of muscular fibers. The individual muscle fiber is penetrated near its center by the nerve, the ends being practically free from nerve influence. The stimulus that comes to the muscle fiber acts primarily upon its center and then travels in both directions to the ends.

Histology of the Muscular Fiber.—A muscular fiber consists of a transparent elastic membrane, the sarcolemma, enclosing the true muscular contents. Examined microscopically, the fiber presents a series of alternate dim and bright bands, giving to it a striated appearance.

When the bright band is examined with high magnifying powers a fine, dark line is seen crossing it transversely. It was supposed by Krause to be the optical expression of a membrane which divides the cavity of the sarcolemma into a series of compartments, each of which contains a dim band of sarcous or muscle substance bounded at either extremity with the half of a bright band. This membrane has since been resolved into a row of granules.

The muscular fiber also exhibits a longitudinal striation indicating that it is composed of fibrillæ, placed side by side and embedded in some interfibrillar substance, to which the name *sarcoplasm* has been given. The fibrillæ which are arranged longitudinally to the long axis of the fiber are grouped by the intervening material into bundles of varying size, the *muscle columns*. The fibrillæ which extend throughout the length of the fiber are not of uniform thickness, but present at regular intervals well-marked constrictions.

In the region of the dim band, the fibrilla presents itself in the form of a homogeneous prismatic rod, termed *sarcostyle*, separated from neighboring rods by a slight amount of sarcoplasm. Between two successive rods is found a dark granule united by a thin band of similar material to the ends of the rods. The transverse row of granules corresponds to Krause's membrane.

In the region of the granules there is a diminution of the sarcous sub-

stance, but an increase in the amount of sarcoplasm, and as the latter is more transparent than the former, the fiber presents at this point a conspicuous bright band. Rollet considers the sarcostyles to be pre-existent, not the result of postmortem or chemic changes, and the seat of the contractile elements. The sarcoplasm is a passive material similar in its properties to protoplasm.

Brücke has shown that when the muscular fiber is examined under crossed Nichol prisms the dim band appears bright and the bright band appears dim against a dark background, indicating that the former is doubly refractile, or anisotropic, the latter singly refractile, or isotropic. The fiber, therefore, appears to be composed of alternate discs of anisotropic and isotropic substance.

Structure of Nonstriated Muscular Fiber.—As the name implies, the involuntary fiber is nonstriated, being apparently uniform and homogeneous in appearance. When isolated the fiber presents itself in the form of an elongated fusiform cell varying from the one-tenth to the one-six hundredth of an inch in length. In some animals the fiber exhibits a longitudinal striation, as if it were composed of fibers. The cell is surrounded by a thin, elastic membrane, and contains a distinct oval nucleus. The fibers are usually arranged in bundles and lamellæ, and held together by a cement substance and connective tissue. This nonstriated muscular tissue is found in the muscularis mucosæ of the alimentary canal as well as in the muscular walls of the stomach and intestines, in the posterior part of the trachea, in the bronchial tubes, in the walls of the blood-vessels, and in many other situations.

Chemic Composition of Muscle.—The chemic composition of muscle is imperfectly understood, owing to the fact that some of its constituents undergo a spontaneous coagulation after death, and that the chemic methods employed also tend to alter its normal composition. When fresh muscle is freed from fat and connective tissue, frozen, rubbed up in a mortar, and expressed through linen, a slightly yellow, syrupy, alkaline, or neutral fluid is obtained, known as *muscle plasma*. This fluid at normal temperature coagulates spontaneously and resembles in many respects the coagulation of blood plasma. The coagulum subsequently contracts and squeezes out an acid *muscle serum*. The coagulated mass is termed *myosin*. This proteid belongs to the class of globulins. Inasmuch as it is not present in living muscle, and only makes its appearance in the as yet living muscle plasma, it is probable that it is derived from some pre existing substance, which is supposed to be *myosinogen*. Myosin is digested by

pepsin and trypsin. According to Halliburton, muscle plasma contains the following proteid bodies: Myosinogen, paramyosinogen, albumin, myoalbumose, all of which differ in chemic composition and respond to various chemic and physical reagents.

Ferment bodies, such as pepsin and diastase; nonnitrogenized bodies, such as glycogen, lactic, and sarcolactic acid, fatty bodies, and inosite; nitrogenized extractives, *e. g.*, urea, uric acid, kreatinin, as well as inorganic salts, have been obtained from the muscle serum.

Metabolism in Muscles.—The chemic changes which underlie the transformation of energy in living muscles are very active and complex.

As shown by an analysis of the blood flowing to and from the resting muscle, it has, while passing through the capillaries, lost oxygen and gained carbon dioxid. The amount of oxygen absorbed by the muscle, nine per cent., is greater than the amount of CO_2 given off, 6.7 per cent. There is no parallelism between these two processes, as CO_2 will be given off in the absence of oxygen, or in an atmosphere of nitrogen.

In the active or contracting muscle both the absorption of oxygen and the production of CO_2 are largely increased, but the ratio existing between them differs considerably from that of the resting muscle, for the quantity of oxygen absorbed amounts to 11.26 per cent, the quantity of CO_2 10.8 per cent. (Ludwig). Moreover, in a tetanized muscle the quantity of CO_2 given off may be largely in excess of the oxygen absorbed. From these facts it is evident that the energy of the contraction does not depend upon the direct oxidation of certain substances, but upon the decomposition of some unstable compound of high potential energy, rich in carbon and oxygen. When the muscle is active, its tissue changes from a neutral to an acid reaction from the development of sarcolactic and possibly phosphoric acids. The amount of glycogen present in muscle, 0.43 per cent., diminishes, but muscles wanting in glycogen, nevertheless, retain their power of contraction. Water is absorbed. The amount of urea is not materially increased by muscular activity, unless it is excessive and prolonged, and then only in the absence of a sufficient quantity of nonnitrogenized material. Coincident with muscular contraction, the blood-vessels become widely dilated, leading to a large increase in the blood supply and a rapid removal of products of decomposition.

Rigor Mortis.—A short time after death the muscles pass into a condition of extreme rigidity or contraction, which lasts from one to five days. In this state they offer great resistance to extension, their tonicity disappears, their cohesion diminishes, their irritability ceases. The time of the

appearance of this postmortem or cadaveric rigidity varies from a quarter of an hour to seven hours. Its onset and duration are influenced by the condition of the muscular irritability at the time of death. When the irritability is impaired from any cause, such as disease or defective blood supply, the rigidity appears promptly, but is of short duration. After death from acute diseases it is apt to be delayed, but to continue for a longer period.

The rigidity appears first in the muscles of the lower jaw and neck; next in the muscles of the abdomen and upper extremities; finally in the trunk and lower extremities. It disappears in practically the same order.

Chemic changes of a marked character accompany this rigidity. The muscle becomes acid in reaction from the development of sarcolactic acid, it gives off a large quantity of carbonic acid, and is shortened and diminished in volume.

The immediate cause of the rigidity appears to be a coagulation of the *myosinogen* within the sarcolemma, with the subsequent formation of *myosin* and muscle serum. In the early stages of coagulation restitution is possible by the circulation of arterial blood through the vessels. The final disappearance of this contraction is due to the action of acids dissolving the myosin, and possibly to putrefactive changes.

Source of Muscular Energy.—According to most experimenters, it is certain that normal muscular activity is not dependent on the metabolism of nitrogenous materials, inasmuch as its chief end product, urea, is not increased. The marked production of CO_2 points to the combustion of some nonnitrogenous matter; *e. g.*, glycogen, especially as this substance disappears during muscular activity. Muscles wanting in glycogen are, nevertheless, capable of contracting for some time. Moreover, there is no proof of the direct combustion of glycogen or any other carbohydrate. It has been suggested by Hermann that the energy of a muscular contraction may be due to the splitting and subsequent re-formation of a complex body belonging neither to the carbohydrates or fats, but to the albumins. To this body the term inogen has been given. This complex molecule, the product of the metabolic activity of the muscle cell, in undergoing decomposition would yield CO_2, sarcolactic acid, and a proteid residue resembling *myosin*. With the cessation of the contraction, the muscle protoplasm recombines the proteid residue with oxygen, carbohydrates, and fats, and again forms inogen.

The phenomena of rigor mortis support such a view. At the moment of this contraction the muscle gives off CO_2 in large amounts, the muscle becomes acid, and myosin is formed. There is thus a close analogy

between the two processes; in other words, a contraction is a partial death of the muscle. As to what becomes of the myosin formed during a contraction, nothing is known. It may be used in the formation of new inogen.

The Physical Properties of Muscular Tissue.—The *consistency* of muscular tissue varies considerably, according to the different states of the muscle. In a state of tension, it is hard and resistant; when free from tension, it is soft and fluctuating, whether the muscle is contracting or resting. Tension alone produces hardness. The *cohesion* of muscular tissue is less than that of connective tissue, and is broken more readily. Cohesion resists traction and pressure, and lasts as long as irritability remains.

The *elasticity* of a muscle, though not great, is almost perfect. After being extended by a weight, it returns to its natural form. The limit of elasticity, however, is soon passed. A weight of 50 or 100 grams will overcome the elasticity so that it will not return to its original length. In inorganic bodies the extension is directly proportional to the extending weight, and the line of extension is straight. With muscles the extension is not proportional to the weight. While at first it is marked, the elongation diminishes as the weight increases by equal increments, so that the line of extension becomes a curve. In other words, the elasticity of a passive muscle increases with increased extension. On the contrary, the elasticity of an active is less than a passive muscle, for it is elongated more by the same weight, as shown by experiment.

Tonicity is a property of all muscles in the body, in consequence of being normally stretched to a slight extent beyond their natural length. This may be due to the action of antagonistic muscles, or to the elasticity of the parts of the skeleton to which they are attached. This is shown by the shortening of the muscle which takes place when it is divided. Muscular tonus plays an important rôle in muscular contraction. Being always on the stretch, the muscle loses no time in acquiring that degree of tension necessary to its immediate action on the bones. Again, the working power of a muscle is increased by the presence of some resistance to the act of contraction. According to Marey, the amount of work is considerably increased when the muscular energy is transmitted by an elastic body to the mass to be moved, while, at the same time, the shock of the contraction is lessened. The position of a passive limb is the resultant also of the elastic tension of antagonistic groups of muscles.

Muscular Excitability or Contractility are terms employed to denote that property of muscular tissue in virtue of which it contracts or shortens in response to various excitants or stimuli. Though usually associated with

the activity of the nervous system, it is, nevertheless, an independent endowment and persists after all nervous connections are destroyed. If the nerve terminals be destroyed, as they can be by the introduction of curara into the system, the muscles become completely relaxed and quiescent. The strongest stimuli applied to the nerves fail to produce a contraction. Various external stimuli applied directly to the muscle substance produces at once the characteristic contraction. The excitability of muscle is there fore an inherent property, dependent on its nutrition and persisting as long as it is supplied with proper nutritive materials and surrounded by those external conditions which maintain its chemic or physical integrity.

Muscular Contractions.—All muscular contractions occurring in the body under normal physiologic conditions are either *voluntary*, caused by a volitional effort and the transmission of a nerve impulse from the brain through the spinal cord and nerves to the muscles; or *reflex*, caused by a peripheral stimulation and the transmission of a nerve impulse to the spinal cord, to be reflected outward through the same nerves to the muscles. In either case the resulting contraction is essentially the same. The *normal* or *physiologic stimulus* which provokes the muscular contraction is a nerve impulse the nature of which is unknown, but is perhaps allied to a molecular disturbance. After removal from the body muscles remain in a state of rest, inasmuch as they possess no spontaneity of action. Though consisting of a highly irritable tissue, they cannot pass from the passive to the active state except upon the application of some form of stimulation.

The stimuli which are capable of calling forth a contraction may be divided into:—

1. Mechanical.
2. Chemic.
3. Physical.
4. Electric.

Every mechanical stimulus of a muscle, *e. g.*, pick, cut, or tap, providing it has sufficient intensity, and is repeated with sufficient rapidity, will cause not only a single but a series of contractions.

All chemic agents which impair the chemic composition of the muscle with sufficient rapidity, *e.g.*, hydrochloric acid, acetic and oxalic acids, distilled water injected in the vessels, etc., act as a stimuli, and produce single and multiple contractions. Physical agents, as heat and electricity, also act as stimuli. A muscle heated rapidly to 30° C. contracts vigorously, and reaches its maximum at 45° C. Of all forms of stimuli the electric is the most generally used. Two forms are used—the induced current and the make-and-break of a constant current.

Changes in a Muscle During Contraction.—When a muscle is stimulated, either indirectly through the nerve or directly by any external agent, it undergoes a series of changes which relate to its form, volume, optical, physical, chemic, and electric properties. These changes in their totality constitute the muscular contraction.

1. *Form.*—The most obvious change is that of form. The fibers become shorter in their longitudinal and wider in their transverse diameters, and the muscle as a whole becomes shorter and thicker. The degree of shortening may amount to 30 per cent. of the original length.
2. *Volume.*—The increase in transverse diameter does not fully compensate for the diminution in length, for there is at the moment of contraction a slight shrinkage in volume, which has been attributed to a compression of air in its interstices.
3. *Optical Changes.*—If a muscular fiber be examined microscopically during its contraction, it will be observed that when the contraction wave begins both bright and dim bands diminish in height and become broader, though this change is more noticeable in the region of the bright band. This Englemann attributes to a passage of fluid material from the bright into the dim band. At the time of relaxation there is a return of this material and the fiber assumes its original shape and volume. As the contraction wave reaches its maximum, the optical properties of both the isotropic and anisotropic bands change. The *former*, which was originally clear, now becomes darker and less transparent, until at the crest of the wave it assumes the appearance of a distinct dark band. The *latter*, the anisotropic, which was originally dim, now becomes, in comparison, clear and light. This change in optical appearance is due to an increase in refrangibility of the isotropic and a decrease in the anisotropic bands coincident with the passage of fluid from the former into the latter. There is at the height of the contraction a complete reversal in the positions of the striations. At a certain stage between the beginning and the crest of the wave there is an intermediate point at which the striæ almost entirely disappear, giving to the fiber an appearance of homogeneity. There is, however, no change in refractive power as shown by the polarizing apparatus. After the contraction wave has reached the stage of greatest intensity, there is a reversal of the above phenomena, and the fiber returns to its original condition, which is one of relaxation.

Physical Changes.—The extensibility of muscle is increased during the contraction, the same weight elongating the fibers to a greater extent than

during rest. The elasticity, or its power of returning to its original form, is correspondingly diminished.

Chemic Changes.—The metabolism of muscle during the contraction is very active. There is an increase in the production of carbon dioxid and the absorption of oxygen. The muscle changes from an alkaline or neutral to an acid reaction, from the development of sarcolactic acid. The muscle also becomes warmer. The electric changes will be treated of in connection with nerves.

Transmission of the Contraction Wave.—Normally, when a muscle is stimulated by the nerve impulse the shortening and thickening of the fibers begin at the end organ and travel in opposite directions to the ends of the muscle. This change propagates itself in a wave-like manner and has been termed the contraction wave. If a stimulus be applied directly to the end of a long muscle, the contraction wave passes along its entire length to the opposite extremity in virtue of the conductivity of muscular tissue. The rapidity of the propagation varies in different animals—in the frog from three to four meters per second, in man from 10 to 13 meters. The length of the wave varies from 200 to 400 millimeters.

Graphic Record of a Muscular Contraction.—The changes in the form of a muscle during contraction and relaxation have been carefully studied by recording the muscular movement by means of an attached lever, the end of which is applied against a traveling surface. The time relations of all phases of the muscular movement are obtained by placing beneath the lever a pen attached to an electro-magnet thrown into action by a tuning fork vibrating in hundredths of a second. A marking lever records simultaneously the moment of stimulation.

Single Contraction.—When a single electric induction shock is applied to a nerve close to the muscle, the latter undergoes a quick pulsation, speedily returning to its former condition. As shown by the muscle curve (see Fig. 2), there is between the moment of stimulation and the beginning of the contraction a short but measurable period, known as the *latent period*, during which certain chemic changes are taking place preparatory to the exhibition of the muscular movement. Even when the electric stimulus is applied directly to the muscle a latent period, though shorter, is observable. The duration of this period in the skeletal muscles of the frog has been estimated at 0.01 of a second, but it has been shown by the employment of more accurate methods and the elimination of various external influences to be much less, not more than 0.0033 to 0.0025 of a second.

The *contraction* follows the latent period. This begins slowly, rapidly reaches its maximum, and ceases. This has been termed the stage of rising or increasing energy. The time occupied in the stage of shortening is about 0.04 of a second, though this will depend on the strength of the stimulus, the load with which the muscle is weighted, and the condition of the muscular irritability.

The *relaxation* immediately follows the contraction. This takes place at first slowly, after which it rapidly returns to its original length. This is the period of falling or decreasing energy and occupies about 0.05 of a second. The whole duration of a muscular contraction occupies, therefore, about 0.1 of a second.

Residual, or after-vibrations, are frequently seen which are due to changes

FIG. 2.—MUSCLE CURVE PRODUCED BY A SINGLE INDUCTION SHOCK APPLIED TO A MUSCLE.

a–f. Abscissa. a–c. Ordinate. a–b. Period of latent stimulation. b–d. Period of increasing energy. d–e. Period of decreasing energy. e–f. Elastic after-vibrations. (*Landois.*)

in the elasticity of the muscle. The *amplitude* of the contraction depends upon the condition of the muscle, the load, the strength of stimulus, etc.

Contraction of Nonstriated Muscle.—The curve obtained by registration of the contraction of nonstriated muscle shows that it is similar in many respects to that of the striated muscle, except that the duration of the former is considerably longer than the latter.

Action of Successive Stimuli.—If a series of successive stimuli be applied to a muscle, the effect will be different according to the rapidity with which they follow each other. If the second stimulus be applied at the termination of the contraction due to the first stimulus, a second contraction follows similar in all respects to the first. A third stimulus produces a third contraction, and so on until the muscle becomes exhausted. If the second stimulus be applied during either of the two periods of the first contraction, the effects of the two stimuli will be added together and the second contraction will add itself to the first. The maximum contrac-

tion is obtained when the second stimulus is applied $\frac{1}{20}$ of a second after the first.

Tetanus.—When a series of stimuli are applied to a muscle following each other with medium rapidity, the muscle does not get time to relax in the intervals of stimulation, but remains in a state of vibratory contraction, which may be regarded as incipient tetanus, or clonus. As the stimulation increases in frequency the vibrations become invisible, being completely fused together. There is, nevertheless, during the tetanic condition a series of continuous contractions and relaxations taking place. After a varying length of time the muscle becomes fatigued, and, notwithstanding the stimulation, begins slowly to elongate. The number of stimuli necessary per second for the production of tetanus varies in different animals; *e. g.*, 2 to 3 for muscles of the tortoise, 10 for muscles of the rabbit, 15 to 20 for the frog, 70 to 80 for the birds, 330 to 340 for insects.

A Voluntary Contraction in man may be regarded as a state of tetanus, for if the curve of a voluntary movement be examined it will be found to consist of intermittent vibrations. The simplest voluntary movement of a muscle, however rapidly it may take place, lasts longer than a single muscular contraction due to an induction shock. The most rapid voluntary contraction is the result of from 2.5 to 4 stimulations per second and has a duration of from 0.041 to 0.064 of a second. A continuous voluntary contraction is an incomplete tetanus. The number of stimuli sent to the muscles is, on the average, 16 to 18 for rapid contractions, 8 to 12 for slow contractions.

The Production of Heat and its Relation to Mechanical Work.—The transformation of energy which takes place during a muscular contraction, and which is dependent upon chemic changes occurring at that time, manifests itself as heat and mechanical work. While heat is being evolved continuously during the passive condition of muscles, the amount of heat is largely increased during general muscular contraction. A skeletal muscle of a frog, *e. g.*, the gastrocnemius, when removed from the body shows, after tetanization, an increase in its temperature of from 0.14° to 0.18° C., and after a single contraction of from 0.001° to 0.005° C. While every muscular contraction is attended by an increase in heat production, the amount so produced will vary in accordance with certain conditions, *e. g.*, tension, work done, fatigue, circulation of blood, etc

Tension.—The greater the tension of a muscle, the greater, other conditions being equal, is the amount of heat evolved. When the ends of a muscle are fastened so that no shortening is possible during stimulation the

maximum of heat production is reached. In the tetanic state the large increase in temperature is due to the tension of antagonistic and strongly contracted muscles. The evolution of heat, therefore, bears a relation to the resistance against which the muscle is acting.

Mechanical Work.—If a muscle contracts loaded by a weight just sufficient to elongate it to its original length, heat is evolved, but no mechanical work is done, all the energy liberated manifesting itself as heat. When the weight which has been lifted is removed from the muscle at the height of contraction, external work is done. In this case the amount of heat liberated is less, owing to the work done, for some of the heat generated is transformed into mechanical motion. According to the law of the conservation of energy, the amount of heat disappearing should correspond in heat units to the number of foot pounds produced by muscular contraction.

Muscle Sound.—Providing a muscle be kept in a state of tension during its contraction, the intermittent variations of its tension cause the muscle to emit an audible sound. If the muscle be tetanized by induction shocks, the pitch of the sound corresponds with the number of stimuli per second. A voluntary contraction is attended by a tone having a vibration frequency of about 36 per second, which is, however, the first overtone of the true muscle tone, which is caused by a contraction frequency of about 18 per second. This low tone is inaudible, from the low rate of vibrations per second.

Muscular Fatigue.—Prolonged or excessive muscular activity is followed by a diminution in the power of producing work and in increase in the duration of the muscular contractions. Fatigue is accompanied by a feeling of stiffness, soreness, and lassitude, referable to the muscles themselves. In the early stages of muscular fatigue, the contractions increase in height and duration, to be followed by a progressive decrease in height, but an increase in duration, until the muscle becomes exhausted. The cause of the fatigue is the production and accumulation of decomposition products, such as phosphoric acid and phosphate of potassium, CO_2, etc. A fatigued muscle is rapidly restored by the injection of arterial blood.

Work Done.—Muscles are machines capable of doing a certain amount of work, by which is meant the raising of a weight against gravity or the overcoming of some resistance. The work done is calculated by multiplying the weight by the distance through which it is raised. Thus, if a muscle shortens four millimeters and raises 250 grams, it does work equal to 1000 milligram-meters, or one gram-meter. If a muscle contracts without being weighted, no work is done. Equally, when the muscle is over-

weighted so that it is unable to contract, no work is done. The amount of work a muscle can do will depend upon the area of its transverse section, the length of its fibers, and the amount of the weight. The amount of work a laborer of 70 kilograms weight performs in eight hours averages 105,605 kilogram-meters, or 340.2 foot tons.

SPECIAL PHYSIOLOGY OF MUSCLES.

The individual muscles of the axial and appendicular portions of the body are named with reference to their shape, action, structure, etc.; *e. g.*, deltoid, flexor, penniform, etc. In different localities, a group of muscles having a common function is named in accordance with the kind of motion it produces or gives rise to; *e. g.*, groups of muscles which alternately bend or straighten a joint, or alternately diminish or increase the angular distance between two bones, are known respectively as *flexors* and *extensors*; such muscular groups are in association with ginglymus joints. Muscles which turn the bone to which they are attached around its own axis without producing any great change of position are known as *rotators*, and are in association with the enarthrodial, or ball-and-socket joints. Muscles which impart an angular movement of the extremities to and from the median line of the body are termed *abductors* and *adductors*.

In addition to the actions of individual groups of muscles in causing special movements in some regions, several groups of muscles are coördinated for the accomplishment of certain definite functions; *e. g.*, muscles of respiration, mastication, expression. The coördination of axial and appendicular muscles enables the individual to assume certain postures, such as standing and sitting; to engage in various acts of locomotion, as walking, running, swimming, etc.

Levers.—The function or special mode of action of individual muscles can only be understood when the bones with which they are connected are regarded as levers whose fulcra or fixed points lie in the joints where the movement takes place, and the muscles as sources of power for imparting movement to the levers with the object of overcoming resistance or raising weights.

In mechanics, levers of three kinds or orders are recognized, according to the relative position of the *fulcrum* or axis of motion, the applied power, and the weight to be moved. See Fig. 3.

In levers of the *first order* the fulcrum, F, lies between the weight or

resistance, W, and the power of moving force, P. The distance PF is known as the power arm, the distance WF as the weight arm. As an example of this form of lever in the human body may be mentioned—

1. The elevation of the trunk from the flexed position. The axis of movement, the fulcrum, lies in the hip joint; the weight, that of the trunk, acting as if concentrated at its center of gravity, placed between the shoulders; the power, the contracting muscles attached to the tuberosity of the ischium. The opposite movement is equally one of the first order, but the relative positions of P and W are reversed.
2. The skull in its movements backward and forward upon the atlas.

In levers of the *second order* the weight lies between the power and the fulcrum. As an illustration of this form of lever may be mentioned—

1. The depression of the lower jaw, in which movement the fulcrum is the temporomaxillary articulation; the resistance, the tension of the elevator muscles; the power, the contraction of the depressor muscles.
2. The raising of the body on the toes—F being the toes, W the weight of the body acting through the ankle, P, the gastrocnemius muscle acting upon the heel bone.

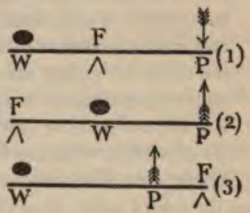

FIG. 3.—THE THREE ORDERS OF LEVERS.

In levers of the *third order* the power is applied at a point lying between the fulcrum and the weight. As examples of this form of lever may be mentioned—

1. The flexion of the forearm—F being the elbow joint, P the contracting biceps and brachialis anticus muscles applied at their insertion, W the weight of the forearm and hand.
2. The extension of the leg on the thigh.

When levers are employed in mechanics, the object aimed at is the overcoming of a great resistance by the application of a small force acting through a great space so as to obtain a mechanical advantage. In the mechanism of the human body the reverse generally obtains, viz., the overcoming of a small resistance by the application of a great force acting through a small space. As a result there is a gain in the extent and rapidity of movement of the lever. The power, however, owing to its point of application, acts at a great mechanical disadvantage in many instances, especially in levers of the third order.

Postures.—Owing to its system of joints, levers, and muscles, the human body can assume a series of positions of equilibrium, such as standing and

sitting, to which the name posture has been given. In order that the body may remain in a state of stable equilibrium in any posture, it is essential that the vertical line passing through the center of gravity shall fall within the base of support.

Standing is that position of equilibrium in which a line drawn through the center of gravity falls within the area of both feet placed on the ground. This position is maintained—

1. By firmly fixing the head on the top of the vertebral column by the action of the muscles on the back of the neck.
2. By making the vertebral column rigid, which is accomplished by the longissimus dorsi and the quadratus lumborum muscles. This having been accomplished, the center of gravity falls in front of the tenth dorsal vertebra; the vertical line passing through this point falls behind the line connecting both hip joints. In consequence, the trunk is not balanced on the hip joints, and would fall backward were it not prevented by the contraction of the rectus femoris muscle and ligaments. At the knees and ankles a similar balancing of the parts above is brought about by the action of various muscles. When the entire body is in the erect or military position, the arms by the sides, the center of gravity lies between the sacrum and the last lumbar vertebra and the vertical line touches the ground between the feet and within the base of support.

Sitting erect is a condition of equilibrium in which the body is balanced on the tubera ischii, when the trunk and head together form a rigid column. The vertical line passes between the tubera.

Locomotion is the act of transferring the body, as a whole, through space, and is accomplished by the combined action of its own muscles. The acts involved consist of walking, running, jumping, etc.

Walking is a complicated act involving almost all the voluntary muscles of the body, either for purposes of progression or for balancing the head and trunk, and may be defined as a progression in a forward horizontal direction, due to the alternate action of both legs. In walking, one leg becomes, for the time being, the active or supporting leg, carrying the trunk and head, the other the passive but progressive leg, to become in turn the active leg when the foot touches the ground. Each leg, therefore, is alternately in an active and passive state.

Running is distinguished from walking by the fact that, at a given moment, both feet are off the ground and the body is raised in the air.

While the limits of a compend do not permit of a description of the origin, insertion, and mode of action of the individual muscles of the body, it has been thought desirable to call attention to a few of the principal muscles

whose function it is to produce special forms of movement, as well as locomotion. (See Fig. 4.) The erect position is largely maintained by the fixation of the spinal column and the balancing of the head upon its upper extremity; the former is accompanied by the *Erector spinæ* muscle, named from its function and its fleshy continuations, situated on each side of the vertebral column. Arising from the pelvis and lumbar vertebræ, this muscle passes upward, and is attached by its continuations to all the vertebræ. Its action is to extend the vertebral column and to maintain the erect position. The head is balanced upon the top of the vertebral column by the combined action of the trapezius and suboccipital muscles forming the nape of the neck, and by the *Sterno-cleido-mastoid* muscle. This latter muscle arises from the inner third of the clavicle and upper border of the sternum. It is inserted into the temporal bone just behind the ear. Its action is to flex the head laterally and to rotate the face to the opposite side. When both muscles act simultaneously the head and neck are flexed upon the thorax.

The *Temporal* and *Masseter* muscles, situated at the side of the head, arise respectively from the temporal fossa and the zygomatic arch and are inserted into the ramus of the lower jaw. Their action is to close the mouth and assist in mastication. The *Occipitofrontalis*, the *Orbicularis palpebrarum*, and *Orbicularis oris* muscles are largely concerned in wrinkling the forehead, closing the eyes and mouth, and in giving various expressions to the face.

The *Deltoid* is a thick, triangular muscle covering the shoulder joint. Arising from the outer third of the clavicle, the acromion process and the spine of the scapula, its fibers converge to be inserted into the humerus just above its middle. Its action is to elevate the arm through a right angle. Owing to its point of insertion it acts as a lever of the third order, but, notwithstanding the advantageous point of insertion, it acts at a considerable disadvantage, owing to the obliquity of its direction.

The *Biceps* muscle, situated on the anterior aspect of the arm, arises from the upper border of the glenoid fossa and the coracoid process, and is inserted into the radius just beyond the elbow joint. Its action is to flex and supinate the forearm and to place it in the most favorable position for striking a blow. When the forearm is fixed it assists in flexing the arm, as in climbing.

The *Triceps* muscle, situated on the back of the arm, arises from the scapula and the posterior surface of the humerus, and is inserted in the olecranon process of the ulna. In its action it directly antagonizes the biceps, namely, extending the forearm. In so doing it acts as a lever of

the first order. The short distance between the muscular insertion and the fulcrum causes it to act at a great mechanical disadvantage, but there is a corresponding gain in both speed and range of movement. The muscles of the forearm are very numerous. Their action is to impart to the forearm and hand a variety of movements, such as pronation, supination, flexion, extension, rotation, etc.

The *Pectoralis Major and Minor* muscles form the fleshy masses of the breast. Arising from the inner half of the clavicle, the side of the sternum, and the outer surfaces of the third, fourth, and fifth ribs anteriorly, the muscular fibers converge to be inserted into the humerus and coracoid process. Their combined action is to adduct, flex, and rotate the arm inward, and to draw the scapula downward and forward, movements necessary to the folding of the arms across the chest.

The *Rectus abdominis* and the *Obliquus externus* assist in forming the abdominal walls.

The *Glutei* muscles are three in number, arranged in layers, and form the fleshy masses known as the buttocks. They arise from the side of the pelvis and are attached to the femur in the neighborhood of the great trochanter. Their action is to extend the hips, to raise the body from the stooping position, to assist in walking by firmly holding the pelvis on the thigh while the opposite leg is advanced in the forward direction.

The *Rectus femoris* with its associates, the rectus internus and externus and crureus, form the fleshy mass on the anterior surface of the thigh. The former arises from the anterior part of the ilium, the latter from the femur. Their common tendon, which is united to the patella, is continued as the ligamentum patellæ, which is attached to the upper part of the tibia. The action of this muscular group is to extend the leg, to flex the thigh, and to raise the entire weight of the body, as in passing from the sitting to the erect position.

The *Biceps femoris* muscle, situated on the outer and posterior aspect of the thigh, arises from the tuber ischii and is inserted into the head of the fibula.

The *Semimembranosus* and the *Semitendinosus* muscles, situated on the inner and posterior aspect of the thigh, are inserted into the head of the tibia. Their combined action is to extend the hips and to flex the knee. Acting from below, they assist in raising the body from the stooping position.

The *Gastrocnemius* muscle forms the enlargement known as the calf of the leg. It arises by two heads from the condyles of the femur. Its tendon, the tendo achillis, is inserted into the posterior surface of the heel

FIG. 4.—SUPERFICIAL MUSCLES OF THE BODY.

bone. Its action is to extend the foot and to raise the weight of the body in walking and running. On the front of the leg are numerous muscles, *e. g.*, *Tibialis anticus*, *Peroneus longus*, etc., the action of which is to flex the foot and to antagonize the gastrocnemius.

PHYSIOLOGY OF NERVOUS TISSUE.

The Nervous Tissue, which unites and coordinates the various organs and tissues of the body and brings the individual into relationship with the external world, is arranged in two systems termed the *Cerebrospinal* and the *Sympathetic*.

The Cerebrospinal System consists in man and the higher animals of—

1. The brain and spinal cord contained within the cavities of the cranium and spinal column respectively, and
2. The cranial and spinal nerves.

The Sympathetic System consists of—

1. A double chain of ganglia connected together by nerves, situated on each side of the spinal column and extending from the base of the skull to the tip of the coccyx.
2. Of various collections of ganglia situated in the head, face, thorax, abdomen, and pelvis; all the ganglia are united by an elaborate system of intercommunicating nerves, many of which are connected with the nerves of the cerebrospinal system.

It is usually stated that the cerebrospinal system is the nervous system of animal life and presides over the functions of motion, sensation, etc., while the sympathetic is the nervous system of organic life and governs the functions of nutrition, growth, secretion, etc. There is reason to believe that this distinction of function between the two systems is not a natural but an artificial one; that the ganglia of the sympathetic system do not possess independent functions, but are rather modifiers of the action of nerves originating in the cerebrospinal system.

Nervous Tissue is composed of two kinds of matter, the *gray* and *white*, which differ in their color, structure, and physiologic endowments; the former consists of *vesicles* or *cells* which receive and generate nerve force; the latter consists of *fibers* which simply conduct it, either from the periphery to the center or the reverse.

Structure of Gray Matter.—The gray matter, found on the surface of the brain, in the convolutions, in the interior of the spinal cord, and in the various ganglia of the cerebrospinal and sympathetic nervous systems, consists of a fine connective tissue stroma, the *neuroglia*, in the meshes of which are embedded the *gray cells* or *vesicles*.

The *cells* are grayish in color, and consist of a delicate investing capsule containing a soft, granular, albuminous matter, a *nucleus*, and sometimes a *nucleolus*. Some of the cells are spherical or oval in shape, while others have an interrupted outline, on account of having one, two, or more processes issuing from them, constituting the *unipolar*, *bipolar*, or *multipolar* nerve cells. Cells vary in size: the smallest being found in the brain, the largest in the anterior horns of the gray matter of the cord. Some of the cell processes become continuous with the fibers of the white matter, while others anastomose with those of adjoining cells.

Structure of White Matter.—The white matter, found for the most part in the interior of the brain, on the surface of the spinal cord, and in almost all the nerves of the cerebrospinal and sympathetic systems, consists of minute fibers cylindrical in form, arranged in bundles held together by connective tissue. The nerve fibers present considerable variation in size in different parts of the nervous system. The largest fibers are found in the peripheral nerves, where they have a diameter of $\frac{1}{2000}$ths of an inch; the smallest are found in the brain and spinal cord, where they have a diameter of only $\frac{1}{5000}$ths of an inch.

A typical nerve fiber presents three well-marked structural elements, *e. g.*:—

1. An external investing membrane, tubular in shape.
2. An intermediate semifluid substance, the medulla or myelin.
3. A dark central thread, the axis cylinder.

Many fibers, however, are devoid of the medulla. This variation in structure has led to the division of the fibers into two groups, viz., the *medullated* and the *nonmedullated*.

Medullated Nerve Fibers.—The external investing membrane of the nerve fiber, generally termed the neurilemma, is thin, transparent, homogeneous, and closely applied to the medulla. Owing to its colorless appearance it can be seen only with difficulty in the recent condition; when treated with various reagents it becomes quite distinct. Physically it is quite resisting and elastic, resembling the sarcolemma of the muscle fiber. Its function is doubtless that of a protecting agent to the more delicate structure contained within it.

The *medulla* or *myelin, the white substance of Schwann*, completely fills the tubular membrane and closely invests the axis cylinder. When the nerve is perfectly fresh, the medulla is clear, transparent, homogeneous highly refractive, and of an oleaginous consistence. When the nerve is subjected to reagents which alter its composition, the medulla becomes opaque and imparts to the nerve a white, glistening appearance. As to the function of the medulla nothing definite is known. By some it is regarded as an insulating agent to the axis cylinder, preventing the diffusion of nerve force to adjoining fibers. Inasmuch as it is wanting in a large proportion of fibers which conduct nerve force without diffusion, it is questionable if this function can be assigned to it with any degree of certainty.

The axis cylinder is in all probabiiity the most essential element of the nerve fiber, as it is the only part uniformly continuous throughout its course. In the natural condition it is transparent and invisible, but when treated with proper reagents, it presents itself as a pale, granular, flattened band, albuminous in composition, more or less solid, and somewhat elastic. The axis is longitudinally striated, showing that it is composed of a number of fibrillæ. This is in all probability the most essential element of the nerve fiber and is the medium of the transmission of nerve force from the center to the periphery and in the reverse direction.

Nodes or Constrictions of Ranvier.—At intervals of about 75 times its diameter the medullated nerve fiber undergoes a remarkable diminution in size, caused by an interruption of the medullary layer, so that the external investment lies directly upon the axis cylinder. These constrictions, taking their name from their discoverer, Ranvier, occur at regular intervals along the course of the nerve, separating it into a series of segments. The portion between the constrictions is known as the internodal segment. It has been supposed that in consequence of the absence of the myelin at the constrictions, a free exchange of nutritive material and decomposition products can take place between the axis cylinder and the plasma.

Nonmedullated Nerve Fibers.—The nonmedullated nerve fibers consist only of an axis cylinder with the external tubular membrane. Though much less abundant than the former variety, they are distributed largely throughout the nervous system, but are particularly abundant in the sympathetic system. Owing to the absence of a medulla they present a rather pale or grayish appearance. Recent investigations would seem to show that all the nerve fibers which come from the spinal cord are at first medullated, but on passing through the sympathetic ganglia they are deprived of the medulla, this being more particularly the case with those branches which are distributed to the blood-vessels and abdominal viscera.

Structure of Nerve Trunks.—After their emergence from the brain and spinal cord, the nerve fibers are bound together by connective tissue into the form of continuous bundles, separate and distinct, which connect the brain and cord with all the remaining structures of the body. These bundles are technically known as nerves or nerve trunks. Each nerve is invested by a thick layer of lamellated connective tissue known as the *epineurium*. A transverse section of a nerve shows that it is made up of a number of small bundles of fibers each of which possesses a separate investment of connective tissue, the *perineurium*. Within this latter mem-

FIG. 5.—TRANSVERSE SECTION OF A NERVE (MEDIAN).
ep. Epineurium. *pe*. Perineurium. *ed*. Endoneurium.

brane are contained the ultimate nerve fibers, supported and separated by a fine stroma, the *endoneurium*. (See Fig. 5.) After pursuing a longer or shorter course, the nerve trunk gives off branches which interlace very freely with neighboring branches, forming a *plexus*, the fibers of which are distributed to associated organs and regions of the body. From their origin to their termination, however, nerve fibers retain their individuality and never become blended with adjoining fibers.

As nerves pass from their origin toward their peripheral terminations

they give off a number of branches, each of which becomes invested with a lamellated sheath which is an off-shoot from that investing the parent trunk. This division of nerve bundles and sheath continues throughout all the branchings down to the ultimate nerve fibers, each of which is surrounded by a sheath of its own, consisting of a single layer of endothelial cells. This transparent membrane, the sheath of Henle, is separated from the nerve fiber by a considerable space, in which is probably contained a quantity of lymph.

Near their ultimate terminations the nerve fibers themselves undergo division, so that a single fiber may give origin to a number of branches, each of which contains a portion of the parent axis cylinder and the myelin.

Nerves are channels of communication between the brain and spinal cord and the muscles, glands, blood-vessels, skin, mucous membrane, etc., in which they ultimately terminate. Any stimulation of a nerve, either in its course or at its termination, develops an excitation which travels throughout the length of the fiber. If the excitation develops a muscular movement, an act of secretion, or a change in the caliber of a blood-vessel, it is termed an *efferent* nerve. If the excitation develops in the brain a conscious sensation, it is termed an *afferent* nerve. As far as can be determined by microscopic and chemic investigations there is no difference between these two classes of fibers.

Nerve Terminations.—

1. *Central.* Both efferent and afferent nerve fibers, as they enter the spinal cord and brain, lose their external investments, and, retaining only the axis cylinder, ultimately become connected with the processes of the gray cells.
2. *Peripheral.* As the nerves approach the tissues to which they are to be distributed, they inosculate freely, forming a *plexus*, from which the ultimate fibers proceed to individual tissues.

Efferent Nerves.—In the *voluntary* or *striped* muscles the efferent nerves are connected with the contractile substance by means of the "*motorial end-plates;*" when the nerve enters the muscular fiber the tubular membrane blends with the sarcolemma, the medullary layer disappears, and the axis cylinder spreads out into the form of a little plate, granular in character, and containing oval nuclei.

In the *unstriped* or *involuntary* muscles, the terminal nerve fibers form a plexus on the muscular fiber cells, and become connected with the granular contents of the nuclei.

In the *glands*, nerve fibers have been traced to the glandular cells, where they form a branching plexus from which fibers pass into their interior and become connected with their substance, and thus influence secretion.

Afferent Nerves terminate in the skin and mucous membranes, in three distinct modes, *e. g.*, as tactile corpuscles, Pacinian corpuscles, and as end bulbs.

The *tactile corpuscles* are found in the papillæ of the true skin, especially on the palmar surface of the hands and fingers, feet and toes; they are oblong bodies, measuring about $\frac{1}{300}$ths of an inch in length, consisting of a central bulb of homogeneous connective tissue surrounded by elastic fibers and elongated nuclei. The nerve fiber approaches the base of the corpuscle, makes two or three spiral turns around it, and terminates in loops. They are connected with the sense of touch.

The *Pacinian corpuscles* are found chiefly in the subcutaneous cellular tissue, on the nerves of the hands and feet, the intercostal nerves, the cutaneous nerves, and in many other situations. They are oval in shape, measure about the $\frac{1}{10}$th of an inch in length on the average, and consist of concentric layers of connective tissue; the nerve fiber penetrates the corpuscle and terminates in a rounded knob in the central bulb. Their *function* is unknown.

The *end bulbs* of Krause are formed of a capsule of connective tissue in which the nerve fiber terminates in a coiled mass or bulbous extremity; they exist in the conjunctiva, tongue, glans penis, clitoris, etc.

Many *afferent* nerves terminate in the papillæ at the base of the hair follicle; but in the skin, mucous membrane, and organs of special sense their mode of termination is not well understood.

PROPERTIES AND FUNCTIONS OF NERVES.

All the nerves which emerge from the brain and spinal cord may be divided, according to the direction in which they carry nerve impulses, into two groups, viz.: *Efferent* and *Afferent*.

The Efferent or **Centrifugal** nerves convey nerve impulses from the brain and spinal cord to various peripheral organs, and may be classified as follows:—

1. *Muscular* or *Motor* nerves, as when they conduct nerve impulses to the muscles and give rise to muscular contraction.
2. *Glandular* or *Secretory* nerves, as when they conduct nerve impulses to glands and excite secretion.

3. *Vascular* or *Vasomotor*, as when they convey nerve impulses to the walls of the blood-vessels, and by stimulating or inhibiting the muscular fibers vary the caliber of the vessel.
4. *Inhibitory*, as when they conduct impulses which inhibit the activity of an organ.

The Afferent or Centripetal nerves convey impulses from the peripheral organs and tissues to the brain and spinal cord and may be classified as follows :—

1. *Sensory-facient* nerves, as when they conduct nerve impulses which give rise in the brain to conscious sensations. They may be subdivided into —
   a. *Nerves of special sense, e. g.*, optic, olfactory, auditory, gustatory; as when they conduct impulses to the brain which give rise to visual, olfactory, auditory, and gustatory sensations.
   b. *Nerves of general sensibility, e. g.*, tactile, thermal, sensory ; as when they conduct impulses to the brain which give rise to sensations of touch, changes of temperature, and pain.
2. *Reflex nerves*, as when they conduct nerve impulses to the nerve centers to be reflected out, through efferent nerves, to muscles, glands, blood-vessels.

Nervous Irritability, Excitability.—These terms are employed to express that condition of a nerve which enables it to conduct nerve impulses from the centers to the periphery, from the periphery to the centers, and to respond to the action of artificial stimuli. A nerve is said to be excitable or irritable as long as it possesses these capabilities or properties. For the manifestation of these properties the nerve must retain a state of physical and chemic integrity ; it must undergo no change in structure or chemic composition. The irritability of an efferent nerve is demonstrated by the contraction of a muscle, the secretion by a gland, a change in the caliber of a blood-vessel, whenever a corresponding nerve is stimulated. The irritability of an afferent nerve is demonstrated by the production of a sensation, or a reflex action whenever it is stimulated. The irritability of nerves continues for a certain period of time after the death of the animal, varying in different classes of animals. In the warm-blooded animals, in which the nutritive changes take place with great rapidity, the irritability soon disappears, a result due to disintegrative changes in the nerve, caused by the withdrawal of the blood supply. In cold-blooded animals, on the contrary, in which the nutritive changes take place relatively slowly, the irritability lasts, under favorable conditions, for a considerable time. Other tissues besides nerves

possess irritability, that is, of responding to the action of stimuli; *e.g.*, glands and muscles, which respond by the production of a secretion or a contraction.

Independence of Tissue Irritability.—The irritability of nerves is distinct and independent of the irritability of muscles and glands, as can be shown by the introduction of various chemic agencies into the circulation. Curara, for example, induces a state of complete paralysis, which is due not to an abolition of the irritability of either the nerve trunks or muscles, but to a modification of the end organs of the nerves just where they come into contact with the muscles. Atropine induces complete suspension of glandular activity by impairing the terminal organs of the secretory nerves just where they are in relation to the gland cells, without destroying the irritability of either gland or nerve.

Stimuli of Nerves.—Nerves do not possess the power of spontaneously generating and propagating nerve impulses; they can only be aroused to activity by the action of an extraneural stimulus. In the living condition, the stimuli capable of throwing the nerve into an active condition act for the most part on either the central or peripheral end of the nerve. In the case of motor nerves the stimulus to the excitation, originating in some molecular disturbance in the nerve cells, acts upon the nerve fibers in connection with them. In the case of sensory or afferent nerves the stimuli act upon the peculiar end organs with which the sensory nerves are in connection, which in turn excite the nerve fibers. Experimentally, it can be demonstrated that nerves can be excited by a sufficiently powerful stimulus applied in any part of their extent.

Nerves respond to stimulation according to their habitual function; thus, stimulation of a sensory nerve, if sufficiently strong, results in the sensation of pain; of the optic nerve, in the sensation of light; of a motor nerve, in contraction of the muscle to which it is distributed; of a secretory nerve, in the activity of the related gland, etc. It is, therefore, evident that peculiarity of nervous function depends neither upon any special construction or activity of the nerve itself, nor upon the nature of the stimulus, but entirely upon the peculiarities of its central and peripheral end organs.

Nerve stimuli may be divided into :—

1. *General stimuli*, comprising those agents which are capable of exciting a nerve in any part of its course.
2. *Special stimuli*, comprising those agents which act upon nerves only through the intermediation of the end organs.

General stimuli :—

1. Mechanical: as from a blow, pressure, tension, puncture, etc.

2. Thermal: heating a nerve at first increases and then decreases its excitability.
3. Chemic: sensory nerves respond somewhat less promptly than motor nerves to this form of irritation.
4. Electric: either the constant or interrupted current.
5. The normal physiologic stimulus:—
   a. Centrifugal or efferent, if proceeding from the center toward the periphery.
   b. Centripetal or afferent, if in the reverse direction.

Special Stimuli:—

1. Light or ethereal vibrations acting upon the end organs of the optic nerve in the retina.
2. Sound or atmospheric undulations acting upon the end organs of the auditory nerve.
3. Heat or vibrations of the air acting upon the end organs in the skin.
4. Chemic agencies acting upon the end organs of the olfactory and gustatory nerves.

As to the nature of the nerve impulse generated by the above stimuli but little is known. It is supposed to be a mode of motion, molecular or vibratory in character, which passes through the axis cylinder with a definite velocity.

Rapidity of Transmission of Nerve Force.—The passage of a nervous impulse, either from the brain to the periphery or in the reverse direction, requires an appreciable period of time. The velocity with which the impulse travels in human sensory nerves has been estimated at about 190 feet per second, and for motor nerves at from 100 to 200 feet per second. The rate of movement is, however, somewhat modified by temperature, cold lessening and heat increasing the rapidity; it is also modified by electric conditions, by the action of drugs, the strength of the stimulus, etc. The rate of transmission through the spinal cord is considerably slower than in nerves, the average velocity for voluntary motor impulses being only 33 feet per second, for sensitive impressions 40 feet, and for tactile impressions 140 feet per second.

Electric Currents in Muscles and Nerves.—If a muscle or nerve be divided and nonpolarizable electrodes be placed upon the natural longitudinal surface at the equator, and upon the transverse section, electric currents are observed with the aid of a delicate galvanometer. The direction of the current is always from the positive equatorial surface to the negative transverse surface. The strength of the current increases or

diminishes according as the positive electrode is moved toward or from the equator. When the electrodes are placed on the two transverse ends of a nerve, an axial current will be observed whose direction is opposite to that of the normal impulse of the nerve.

The *electromotive force* of the strongest nerve current has been estimated to be equal to the 0.026 of a Daniell battery; the force of the current of the frog muscle about 0.05 to 0.08 of a Daniell.

Negative Variation of Currents in Muscles and Nerves.—If a muscle or nerve be thrown into a condition of tetanus, it will be observed that the currents undergo a diminution or negative variation, a change which passes along the nerve in the form of a wave and with a velocity equal to the rate of transmission of the nerve impulse. The wave length of a single negative variation has been estimated to be 18 millimeters; the period of its duration being from 0.0005 to 0.0008 of a second.

It is asserted by Hermann that perfectly fresh, uninjured muscles and nerves are devoid of currents, and that the currents observed are the result of a molecular death at the point of section, this point becoming negative to the equatorial point. He applies the term "action currents" to the currents obtained when a muscle is thrown into a state of activity.

Electric Properties of Nerves.—When a galvanic current is made to flow along a motor nerve from the center to the periphery, from the positive to the negative poles, it is known as the *direct*, *descending*, or *centrifugal* current. When it is made to flow in the reverse direction, it is known as the *inverse*, *ascending*, or *centripetal* current.

The passage of a direct current enfeebles the excitability of a nerve; the passage of the inverse current increases it. The excitability of a nerve may be exhausted by the repeated applications of electricity; when thus exhausted it may be restored by repose, or by the passage of the inverse current if the nerve has been exhausted by the direct current, or vice versa.

During the actual passage of a feeble constant current in either direction neither pain nor muscular contraction is ordinarily manifested; if the current be very intense, the nerve may be disorganized and its excitability destroyed.

Electrotonus.—The passage of a direct galvanic current through a portion of a nerve excites in the parts beyond the electrodes a condition of electric tension or *electrotonus*, during which the *excitability* of the nerve is *decreased* near the anode or positive pole, and *increased* near the cathode or negative pole; the increase of excitability in the *catelectrotonic area*, that nearest the muscle, being manifested by a more marked contraction of

the muscle than the normal, when the nerve is irritated in this region. The passage of an *inverse* galvanic current excites the same condition of electrotonus; and the *diminution* of excitability near the anode, the *anelectrotonic area*, that is now nearest the muscle, being manifested by a less marked contraction than the normal when the nerve is stimulated in this region. Between the electrodes is a neutral point where the catelectrotonic area emerges into the anelectrotonic area. If the current be a strong one, the neutral point approaches the cathode; if weak, it approaches the anode.

When a nervous impulse passes along a nerve, the only appreciable effect is a change in its electric condition, there being no change in its temperature, chemic composition, or physical condition. The natural nerve currents, which are always present in a living nerve as a result of its nutritive activity, in great part disappear during the passage of an impulse, undergoing a *negative variation*.

Law of Contraction.—If a *feeble* galvanic current be applied to a recent and excitable nerve, contraction is produced in the muscles only upon the *making* of the circuit with both the direct and inverse currents.

If the current be *moderate* in intensity, the contraction is produced in the muscle both upon the *making* and *breaking* of the circuit, with both the direct and inverse currents.

If the current be *intense*, contraction is produced only when the circuit is *made* with the direct current, and only when it is *broken* with the inverse current.

The Reaction of Degeneration.—Two different applications of electricity are used in electrophysiology and electrotherapeutics—the constant or galvanic, and the interrupted or faradic currents. Injured and paralyzed muscles and nerves react differently to these two kinds of stimuli, and the facts are of the greatest importance in the diagnosis and therapeutics of the precedent lesions. The principal difference of behavior relates to the *reaction of degeneration*—a condition produced by paralysis of any kind. It is characterized by a diminished or abolished excitability of the muscles to the faradic current, while there is at the same time an increased excitability to the galvanic current. The synchronous diminished excitability of the nerves is the same for either current. The term partial reaction of degeneration is used when there is a normal reaction of the nerves, but the muscles show the degenerative reaction. This condition is a characteristic of progressive muscular atrophy.

Reflex Action.—Many of the muscular, glandular, and vascular reac-

tions which are exhibited by different portions of the body are comprised under the term reflex action, for the reason that they are the immediate results of stimulations of afferent nerves at their peripheral terminations and, in a general way, may be said to take place independently of the brain.

The conversion of an afferent impulse into an efferent impulse takes place in a nerve center, termed a reflex center. The parts involved in any reflex act are as follows:—

1. A sentient surface: skin, mucous membrane, sense organ, etc.
2. An afferent nerve fiber.
3. A receptive center in connection with the afferent nerve.
4. A commissural tract.
5. An emissive center in connection with the efferent nerve.
6. An efferent nerve.
7. A responsive organ, muscle, gland, blood-vessel, etc.

A stimulus of sufficient intensity applied to a sentient surface develops in the afferent nerve a series of nerve impulses which, traveling inward to the centers, are converted into efferent impulses and reflected outward to either muscle, gland, or blood-vessel, or all three simultaneously with the production of muscular contraction, glandular secretion, vascular contraction or dilatation.

The reflex actions take place for the most part through the spinal cord and medulla oblongata, which, in virtue of their contained centers, coördinate the various organs and tissues concerned in the performance of the organic functions. The movements of mastication, the secretion of saliva, the muscular, glandular, and vascular phenomena of gastric and intestinal digestion, the respiratory movements, the mechanism of micturition, etc., are illustrations of reflex activity. (See function of spinal cord.)

FOODS AND DIETETICS.

During the functional activity of every organ and tissue of the body the living material of which it is composed, the *protoplasm*, undergoes more or less disintegration. Through a series of descending chemic stages it is reduced to a number of simpler compounds which are of no further value to the body and which are in consequence eliminated by the various eliminating or excretory organs: the lungs, kidneys, skin, liver. Among these compounds the more important are carbon dioxid, urea, and uric acid. Many other compounds, inorganic as well as organic, are also eliminated by the water discharged from the body in which they are held in solution.

Coincident with this disintegration of the tissues there is an evolution or disengagement of energy particularly in the form of heat.

In order that the tissues may regain their normal composition and thus be enabled to continue in the performance of their functions, they must be supplied with the same nutritive materials of which their protoplasm originally consisted, viz.: water, inorganic salts, proteids, sugar, fat. These materials are furnished by the blood during its passage through the capillary blood-vessels. The blood is a reservoir of nutritive material in a condition to be absorbed, organized, and transformed into new living tissue.

Inasmuch as the loss of material from the body daily, which is very great, is supplied under other forms by the blood, it is evident that this fluid would rapidly diminish in volume were it not restored by the introduction of new and corresponding materials. As soon as the blood volume falls to a certain extent, the sensations of hunger and thirst arise, which in a short time lead to the necessity of taking food.

In addition to the direct appropriation of food by the tissues it is highly probable that an indefinite amount undergoes oxidation and disintegration without ever becoming an integral part of the tissues, and thus directly contributes to the production of heat.

Inanition or Starvation.—If these nutritive principles be not supplied in sufficient quantity, or if they are withheld entirely, a condition of physiologic decay is established, to which the term inanition or starvation is applied. The phenomena which characterize this pathologic process are as follows, viz.: hunger, intense thirst, gastric and intestinal uneasiness and pain, muscular weakness and emaciation, a diminution in the quantity of carbon dioxid exhaled, a lessening in the amount of urine and its constituents excreted, a diminution in the volume of the blood, an exhalation of a fetid odor from the body, vertigo, stupor, delirium, and at times convulsions, a fall of bodily temperature, and finally death from exhaustion.

During starvation the loss of different tissues, before death occurs, averages $\frac{4}{10}$ths, or 40 per cent., of their weight.

Those tissues which lose *more* than *40 per cent.* are fat, 93.3; blood, 75; spleen, 71.4; pancreas, 64.1; liver, 52; heat, 44.8; intestines, 42.4; muscle, 42.3. Those which lose *less* than *40 per cent.* are the muscular coat of the stomach, 39.7; pharynx and esophagus, 34.2; skin, 33.3; kidneys, 31.9; respiratory apparatus, 22.2; bones, 16.7; eyes, 10; nervous system, 1.9.

The *fat* entirely disappears, with the exception of a small quantity which remains in the posterior portion of the orbits and around the kidneys. The *blood* diminishes in volume and loses its nutritive properties. The

muscles undergo a marked diminution in volume and becomes soft and flabby. The *nervous system* is last to suffer, not more than two per cent. disappearing before death occurs.

The *appearances* presented by the body after death from starvation are those of anemia and great emaciation; almost total absence of fat; bloodlessness; a diminution in the volume of the organs; an empty condition of the stomach and bowels, the coats of which are thin and transparent. There is a marked disposition of the body to undergo decomposition, giving rise to a very fetid odor.

The *duration of life* after a complete deprivation of food varies from eight to thirteen days, though life can be maintained much longer if a quantity of water be obtained. The water is more essential under these circumstances than the solid matters, which can be supplied by the organism itself.

The different alimentary or nutritive principles which are appropriated by the tissues and which are contained within the various articles of food, belong to both the organic and inorganic groups and chemic compounds, and may be classified according to their composition as follows :—

CLASSIFICATION OF ALIMENTARY PRINCIPLES.

1. Proteid Group.—Nitrogenized, C. O. H. N. S. P

Principle.	*Where Found.*
Myosin,	Flesh of animals.
Vitellin albumin,	Yolk of egg, white of egg.
Fibrin, globulin,	Blood contained in meat.
Casein,	Milk, cheese.
Gluten,	Grain of wheat and other cereals.
Vegetable albumin,	Soft growing vegetables.
Legumin,	Peas, beans, lentils, etc.
Gelatin,	Bones.

2. Oleaginous Group.—C. O. H.

Animal fats and oils, *Stearin, olein*, *Palmitin, fatty acids*,	Found in the adipose tissue of animals, seeds, grains, nuts, fruits, and other vegetable tissues.

3. Carbohydrate Group.—C. O. H.

Saccharose, or *cane sugar*,	Sugar cane.
Dextrose, or *glucose*, *Levulose*, or *fruit sugar*,	Fruits.
Lactose, or *milk sugar*,	Milk.
Maltose,	Malt, malt foods.
Starch,	Cereals, tuberous roots, and leguminous plants.
Glycogen,	Liver, muscles.

4. **Inorganic Group.**—Water, sodium and potassium chlorids, sodium, calcium, magnesium and potassium phosphates, calcium carbonate, and iron.

5. **Vegetable Acid Group.**—Malic, citric, tartaric, and other acids, found principally in fruits.

6. **Accessory Foods.**—Tea, coffee, alcohol, cocoa, etc.

The proteid principles of the food after undergoing digestion and conversion into peptones are absorbed and transformed into the form of proteids characteristic of the blood plasma and the lymph. Of the proteids thus brought into relation with the living protoplasm, a small percentage only is utilized in the repair of its substance. This is known as *tissue proteid.* A large percentage circulating among and permeating the tissues is acted upon by them directly, and reduced to simpler compounds without ever becoming a part of the tissue itself. This is known as *circulating proteid.* In the process of tissue metabolism all the proteids suffer disintegration and give rise to the production of some carbon-holding compound, probably fat, and some nitrogen-holding compounds which eventually produce urea. The intermediate stages are possibly represented by glycin, creatin, uric acid, etc. An excess of proteids in the food is followed by their decomposition, by the pancreatic juice, into leucin and tyrosin, which by the agency of the liver are converted into urea. The disintegration of the proteids is attended by the disengagement of heat: they thus contribute to the energy of the body.

The oleaginous principles after digestion are absorbed into the blood, from which they rapidly disappear. It is probable that a portion of the fat enters directly into the composition of living protoplasm, out of which it again emerges at some subsequent stage in the form of small drops which make their appearance in the protoplasmic cells of the connective areolar tissue, thus giving rise to the adipose tissue. Another portion probably undergoes direct oxidation.

The carbohydrate principles after digestion are absorbed as dextrose and temporarily stored up in the liver as glycogen. The intermediate stages which sugar passes through and the combinations into which it enters between its absorption and its elimination are but imperfectly understood. That it contributes to the accumulation of fat is probable, though it is doubtful if it is ever converted into fat. A large percentage of the sugar absorbed is at once oxidized. The reduction of fat and sugar to carbon dioxid and water, under which forms they are eliminated from the body, is accompanied by the disengagement of a large quantity of heat.

Water is present in all the fluids and solids of the body. It promotes

the absorption of new material from the alimentary canal; it holds the various ingredients of the blood, lymph, and other fluids in solution; it hastens the absorption of waste products from the tissues, and promotes their speedy elimination from the body.

Sodium chlorid is present in all parts of the body to the extent of 110 gm. The average amount eliminated daily is 15 gm. Its necessity as an article of diet is at once apparent. Taken as a condiment, it imparts sapidity to the food, excites the flow of the digestive fluids, promotes the absorption and assimilation of the albumins, influences the passage of nutritive material through animal membranes, and furnishes the chlorin for the free hydrochloric acid of the gastric juice. In some unknown way it favorably promotes the activity of the general nutritive process.

The potassium salts are also essential to the normal activity of the nutritive process. When deprived of these salts animals become weak and emaciated. When given in small doses they increase the force of the heart beat, raise the arterial pressure, and thus increase the action of the circulation of the blood.

The calcium phosphate and carbonate are utilized in imparting solidity to the tissues, more especially the bones and teeth. Many articles of food contain these salts in quantities sufficient to restore the amount lost daily.

The vegetable acids increase the secretions of the alimentary canal and are apt, in large amounts, to produce flatulence and diarrhea. After entering in combination with bases to form salts, they stimulate the action of the kidneys and promote a larger elimination of all the urinary constituents. In some unknown way they influence nutrition; when deprived of these acids the individual becomes scorbutic.

The accessory foods, coffee and tea, when taken in moderation, overcome the sense of fatigue and mental unrest consequent on excessive physical and mental exertion. Coffee increases the action of the intestinal glands and acts as a laxative. After absorption, its active principle, *caffein*, stimulates the action of the heart, raises the arterial pressure, and excites the action of the brain. Tea acts as an astringent, owing to the tannic acid it contains. One effect of the tannic acid is to coagulate the digestive ferments and to interfere with the activity of the digestive process.

Alcohol, when introduced into the system in *small quantities*, undergoes oxidation and contributes to the production of force, and is thus far a food. It excites the gastric glands to increased secretion, improves the digestion, accelerates the action of the heart, and stimulates the activities of the nervous centers. In zymotic diseases, and all cases of depression of the vital powers, it is most useful as a restorative agent. When taken in

excessive quantities it is eliminated by the lungs and kidneys. The metamorphosis of the tissue is retarded, the elimination of urea and carbonic acid is lessened, the temperature lowered, the muscular powers impaired, and the resistance to depressing external influences diminished. When taken through a long period of time, alcohol impairs digestion, produces gastric catarrh, disorders the secreting power of the hepatic cells. It also diminishes the muscular power and destroys the structure and composition of the cells of the brain and spinal cord. The connective tissue of the body increases in amount, and subsequently contracting, gives rise to sclerosis.

A Proper Combination of different alimentary principles is essential for healthy nutrition, no one class being capable of maintaining life for any definite length of time.

The *albuminous food* in excess promotes the arthritic diathesis, manifesting itself as gout, gravel, etc.

The *oleaginous food* in excess gives rise to the bilious diathesis, while a deficiency of it promotes the scrofulous.

The *farinaceous food*, when long continued in excess, favors the rheumatic diathesis by the development of lactic acid.

The Quantities of the different nutritive materials which are required daily for the growth and repair of the tissues and for the evolution of heat have been variously estimated by different observers. The following table shows the average diet scale of Vierordt, and the amount of waste products to which it would give rise:—

COMPARISON OF THE INGESTA AND EGESTA.

Ingesta.		*Egesta.*	
Proteids, ...	120 grams.	Urea, ...	40 grams.
Fat, ...	90 "	Inorganic salts, .	32 "
Starch, ...	330 "	Feces, ...	104 "
Inorganic salts, .	32 "	Carbon dioxid, .	800 "
Water, ...	2800 "	Water, ...	3096 "
Oxygen, ...	700 "		
Total, . . .	4072 "	Total, . . .	4072 "

Other estimates as to the amounts of the organic substances required daily are as follows:—

	Ranke.	*Voit.*	*Moleschott.*
Proteid, . . .	100	118	130 grams.
Fat, ...	100	50	84 "
Starch, . . .	240	500	404 "

The Energy of the Animal Body.—The food consumed daily not only repairs the loss of material from the body, but also furnishes the energy to replace that which is expended daily in the shape of heat and motion. All the energy of the body can be traced to the chemic changes going on in the tissues and more particularly to those changes involved in the oxidation of the foods.

The amount of heat yielded by any given food principle can be determined by burning it to carbon dioxid and water, and ascertaining the extent to which it will, when so liberated, raise the temperature of a given volume of water. This amount of heat may be expressed in gram degrees of heat, *i. e.*, calories or kilogrammeters of work. A calory is the amount of heat required to raise the temperature of *one gram* of water *one degree* Centigrade. A kilogrammeter of work is the amount of heat required to raise *one kilogram* one meter in height.

The following estimates give, approximately, the number of calories produced when the food is reduced within the body to urea, carbon dioxid, and water :—

1	gram of	proteid	yields	4500	calories.
1	"	fat	"	9000	"
1	"	starch	"	4000	"

The total number of calories or gram degrees of heat yielded by any given diet scale can be readily determined by multiplying the above factors by the quantities of material consumed. The diet scale of Ranke, for example, yields the following amount :—

100	grams of	proteid	yield	450,000	calories.
100	"	fat	"	900,000	"
240	"	starch	"	960,000	"
	Total, ...			2,310,000	"

It has also been determined experimentally that one gram of proteid, one gram of fat, and one gram of starch, when completely oxidized, will yield energy sufficient to do 1850, 3841, and 1657 kilogrammeters of work, respectively.

The total energy of the Ranke diet scale can be easily calculated, *e. g.* :—

100	grams of	proteid	yield	185,000	kilogrammeters.
100	"	fat	"	384,100	"
240	"	starch	"	397,680	"
	Total, ...			966,780	"

It will be thus seen that the food consumed daily yields 2,310,000 *gram degree* units of heat, or 2310 *kilogram degree* units, which can be translated into its mechanical equivalent, 966,780 kilogrammeters of work.

The Amount of Food required in twenty-four hours is estimated from the total quantity of carbon and nitrogen excreted from the body in twenty-four hours, these two elements representing the waste or destruction of the carbonaceous and nitrogenized compounds. It has been determined by experimentation that about 4600 grains of carbon and about 300 grains of nitrogen are eliminated from the body daily, the ratio being about 15 to 1. That the body may be kept in its normal condition, a proper proportion of carbonaceous (bread) to nitrogenized (meat) food should be observed in the diet.

The method of determining the proper amounts of both kinds of food is as follows:—

1000 grs. of bread (2 oz.) contain 300 grs. C. and 10 grs. N.

To obtain the requisite amount of nitrogen from bread, 30,000 grains, or about four pounds, containing 900 grains of carbon and 300 of nitrogen, would have to be consumed. Under such a diet there would be a large excess of carbon, which would be undesirable. On a meat diet the reverse obtains:—

1000 grs. of meat (2 oz.) contain 100 grs. C. and 30 grs. N.

To obtain the requisite amount of carbon from meat, 45,000 grains, or about 6½ pounds, containing 4500 grains of carbon and 1350 grains of nitrogen, would have to be consumed. Under such circumstances there would arise an excess of nitrogen in the system, which would be equally undesirable and injurious. By combining these two articles, however, in proper proportion, the requisite amounts of carbon and nitrogen can be obtained without any excess of either, *e.g.*:—

2 lbs. of bread	contain	4630 grs. C.	and	154 grs. N.
¾ " meat	"	463 " "	"	154 " "
		5093 C.		308 N.

The amount of carbon and nitrogen necessary to compensate for the loss to the system daily would be contained in the above amount of food. As about 3½ ounces of oil or butter are consumed daily, the quantity of bread can be reduced to 19 oz. In the quantities of bread and meat above mentioned, there are 4.2 oz. albumin, 9.3 sugar and starch.

The Alimentary Principles are not introduced into the body as such, but are combined in proper proportions to form compound substances, termed *foods*, *e.g.*, bread, milk, eggs, meat, etc., the nutritive value of each depending upon the extent to which these principles exist.

The following tables show the average composition of various articles of food:—

COMPOSITION OF ANIMAL FOODS.

In 100 Parts.	Beef.	Veal.	Mutton.	Pork.	Fowl.	Fish.
Water, ...	76.25	77.82	75.59	72.57	70.80	79.30
Proteid, . . .	20.24	19.86	17.11	19.31	22.70	18.30
Fat, ...	1.68	0.82	5.47	5.82	4.10	0.70
Carbohydrates,	0.50	0.80	0.60	0.60	1.20	0.90
Salts, ...	1.38	0.70	1.23	1.70	1.20	0.80

COMPOSITION OF VEGETABLE FOODS.

In 100 Parts.	Beans.	Peas.	Potatoes	Turnips.	Cabbage.	Asparagus.
Water, ...	13.74	14.99	75.47	89.42	89.97	93.75
Proteid, . . .	23.21	22.85	1.95	1.35	1.89	1.79
Fat, ...	2.14	1.79	0.15	0.18	0.20	0.25
Carbohydrates,	53.67	52.36	20.69	7.36	4.87	2.63
Cellulose, . .	3.69	5.43	0.76	0.94	1.84	1.04
Salts, ...	3.55	2.58	0.98	0.75	1.23	0.54

COMPOSITION OF CEREAL FOODS.

In 100 Parts.	Wheat.	Rye.	Barley.	Oats.	Corn.	Rice.
Water, ...	13.56	12.65	13.77	12.37	13.10	13.12
Proteid, . . .	12.35	12.55	11.14	10.41	9.85	7.88
Fat, ...	1.75	1.97	2.16	5.23	4.57	0.85
Carbohydrates,	67.90	67.95	64.93	57.78	68.42	76.55
Cellulose, . .	2.63	3.00	5.31	11.19	2.50	0.55
Salts, ...	1.81	1.88	2.69	3.02	1.56	1.05

DIGESTION.

Digestion is a physical and chemic process, by which the food introduced into the alimentary canal is liquefied and its nutritive principles transformed by the digestive fluids into new substances capable of being absorbed into the blood.

The Digestive Apparatus consists of the alimentary canal and its appendages, viz.: teeth, salivary, gastric, and intestinal glands, liver, and pancreas.

Digestion may be divided into *seven stages:* prehension, mastication, insalivation, deglutition, gastric and intestinal digestion, and defecation.

Prehension, the act of conveying food into the mouth, is accomplished by the hands, lips, and teeth.

MASTICATION.

Mastication is the trituration of the food, and is accomplished by the teeth and lower jaw under the influence of muscular contraction. When thoroughly divided, the food presents a greater surface for the solvent action of the digestive fluids, thus aiding the general process of digestion.

The Teeth are 32 in number, 16 in each jaw, and divided into 4 in-

cisors or cutting teeth, 2 canines, 4 bicuspids, and 6 molars or grinding teeth; each tooth consists of a crown covered by enamel, a neck, and a root surrounded by the crusta petrosa and imbedded in the alveolar process; a section through a tooth shows that its substance is made of *dentine*, in the center of which is the pulp cavity, containing blood-vessels and nerves.

The *lower jaw* is capable of making a downward and an upward, a lateral and an anteroposterior movement, dependent upon the construction of the temporomaxillary articulation.

The jaw is *depressed* by the contraction of the *digastric*, *geniohyoid*, *mylo hyoid*, and *platysma myoides* muscles; *elevated* by the *temporal*, *masseter*, and *internal pterygoid* muscles; moved *laterally* by the alternate contraction of the *external pterygoid* muscles; moved *anteriorly* by the *pterygoid*, and *posteriorly* by the united actions of the *geniohyoid*, *mylohyoid*, and posterior fibers of the *temporal* muscle.

The food is kept between the teeth by the *intrinsic* and *extrinsic* muscles of the tongue from within, and the *orbicularis oris* and *buccinator* muscles from without.

The Movements of Mastication, though originating in an effort of the will and under its control, are, for the most part, of an automatic or reflex character, taking place through the medulla oblongata and induced by the presence of food within the mouth. The nerves and nerve centers involved in this mechanism are shown in the following table:—

NERVOUS CIRCLE OF MASTICATION.

Afferent or Excitor Nerves.	*Efferent or Motor Nerves.*
1. Lingual branch of 5th pair.	1. 3d branch of 5th pair.
2. Glossopharyngeal.	2. Hypoglossal.
	3. Facial.

The impressions made upon the terminal filaments of the sensory nerves are transmitted to the medulla; motor impulses are here generated which are transmitted through motor nerves to the muscles involved in the movements of the lower law. The medulla not only generates motor impulses, but coördinates them in such a manner that the movements of mastication may be directed toward the accomplishment of a definite purpose.

INSALIVATION.

Insalivation is the incorporation of the food with the saliva secreted by the *parotid*, *submaxillary*, and *sublingual glands;* the *parotid* saliva, thin and watery, is poured into the mouth through Steno's duct; the *sub-*

maxillary and *sublingual* salivas, thick and viscid, are poured into the mouth through Wharton's and Bartholini's ducts.

In their minute structure the salivary glands resemble each other. They belong to the racemose variety, and consist of small sacs or vesicles, which are the terminal expansions of the smallest salivary ducts. Each vesicle or *acinus* consists of a basement membrane surrounded by blood-vessels and lined with epithelial cells. In the parotid gland the lining cells are granular and nucleated; in the submaxillary and sublingual glands the cells are large, clear, and contain a quantity of mucigen. During and after secretion very remarkable changes take place in the cells lining the acini, which are in some way connected with the essential constituents of the salivary fluids.

In a living serous gland, *e. g.*, parotid, during rest, the secretory cells lining the acini of the gland are seen to be filled with fine granules, which are often so abundant as to obscure the nucleus and enlarge the cells until

FIG. 6.—CELLS OF THE ALVEOLI OF A SEROUS OR WATERY SALIVARY GLAND. A. After rest. B. After a short period of activity. C. After a prolonged period of activity.—(*Yeo's Text-Book of Physiology.*)

the lumen of the acinus is almost obliterated. (See Fig. 6.) When the gland begins to secrete the saliva, the granules disappear from the outer boundary of the cells, which then become clear and distinct. At the end of the secretory activity the cells have become free of granules, have become smaller and more distinct in outline. It would seem that the granular matter is formed in the cells during the rest, and discharged into the ducts during the activity of the gland.

In the mucous glands, *e. g.*, submaxillary and sublingual, the changes that occur in the cells are somewhat different. (See Fig. 7.) During the intervals of digestion the cells lining the gland are large, clear, and highly refractive, and contain a large quantity of mucigen. After secretion has taken place the cells exhibit a marked change. The mucigen cells have disappeared, and in their place are cells which are small, dark, and com-

posed of protoplasm. It would appear that the cells, during rest, elaborate the mucigen which is discharged into the tubules during secretory activity, to become part of the secretion.

Saliva is an opalescent, slightly viscid, alkaline fluid, having a specific gravity of 1.005. Microscopic examination reveals the presence of salivary corpuscles and epithelial cells. Chemically it is composed of water, proteid matter, a ferment (*ptyalin*), and inorganic salts. The amount secreted in twenty-four hours is about 2½ lbs. Its function is twofold:—

1. *Physical.*—Softens and moistens the food, glues it together, and facilitates swallowing.
2. *Chemic.*—Converts *starch* into *sugar*. This action is due to the

FIG. 7.—SECTION OF A "MUCOUS" GLAND.
A. In a state of rest. B. After it has been for some time actively secreting.—(*Lavdowsky.*)

presence of the organic ferment, ptyalin. Ptyalin is an amorphous nitrogenized substance, which can be precipitated from the saliva by calcium phosphate. Its power of converting starch into sugar is manifested most decidedly at the temperature of the living body and in a slightly alkaline medium. The conversion of starch into sugar takes place through several stages, the nature of which depends upon the structure of the starch granule. This consists of two portions, a stroma of cellulose and a contained material, *granulose*, which is the more abundant and important of the two. When subjected to the action of boiling water the starch granule swells up and bursts, forming a viscid, opalescent mass of starch paste. If saliva be now added to this paste and kept at a

temperature of 104° F. for a few minutes, the paste becomes clear and limpid. The first stage in the digestion is now complete with the formation of soluble starch. If the action of saliva be continued, a number of substances intermediate between starch and sugar are formed, to which the name dextrin has been given. Among these may be mentioned:—

a. *Erythrodextrin*, which gives the reddish brown color with iodin. As the digestion continues and sugar is formed the erythrodextrin disappears, giving way to—

b. *Achroödextrin*, which yields no coloration with iodin but which may be precipitated with alcohol.

The sugar formed by the action of saliva is *maltose*, the formula for which is $C_{12}H_{22}O_{11}$. A small quantity of dextrose is also formed.

NERVOUS CIRCLE OF INSALIVATION.

Afferent or Excitor Nerves.	*Efferent or Secretory Nerves.*
1. Lingual branch of 5th pair.	1. Auriculotemporal branch of 5th pair, for parotid gland.
2. Glossopharyngeal.	2. Chorda tympani, for submaxillary and sublingual glands.

The centers regulating the secretion are two, viz.: The medulla oblongata and the submaxillary ganglion of the sympathetic, the latter acting antagonistically to the former. Impressions excited by the food in the mouth reach the medulla oblongata through the afferent nerves; motor impulses are there generated which pass outward through the efferent nerves.

Stimulation of the auriculotemporal branch increases the flow of saliva from the parotid gland; *division* arrests it.

Stimulation of the chorda tympani is followed by a dilatation of the blood-vessels of the submaxillary gland, increased flow of blood (thus acting as a vasodilator nerve), and an abundant discharge of a thin saliva; *division* of the nerve arrests the secretion.

Stimulation of the cervical sympathetic is followed by a contraction of the blood-vessels, diminishing the flow of blood (thus acting as a vasoconstrictor nerve), and a diminution of the secretion, which now becomes thick and viscid; *division* of the sympathetic does not, however, completely dilate the vessels. There is evidence of the existence of a local vasomotor mechanism, which is *inhibited* by the chorda tympani, *exalted* by the sympathetic.

DEGLUTITION.

Deglutition is the act of transferring food from the mouth into the stomach, and may be divided into *three* stages:—

1. The passage of the bolus from the mouth into the pharynx.
2. From the pharynx into the esophagus.
3. From the esophagus into the stomach.

In the *first stage*, which is entirely voluntary, the mouth is closed and respiration momentarily suspended; the tongue, placed against the roof of the mouth, arches upward and backward, and forces the bolus into the fauces.

In the *second stage*, which is entirely reflex, the palate is made tense and directed upward and backward by the levatores-palati and tensores-palati muscles; the bolus is grasped by the superior constrictor muscle of the pharynx and rapidly forced into the esophagus.

The food is prevented from entering the *posterior nares* by the uvula and the closure of the posterior half-arches (the palatopharyngeal muscles); from entering the *larynx* by its ascent under the base of the tongue and the action of the epiglottis.

In the *third stage*, the longitudinal and circular muscular fibers, contracting from above downward, *strip* the bolus into the stomach. (For Nervous Mechanism of Deglutition, see Medulla Oblongata.)

GASTRIC DIGESTION.

The Stomach.—Immediately beyond the termination of the esophagus the alimentary canal expands and forms a receptacle for the temporary retention of the food. To this dilatation the term stomach has been applied. This organ is somewhat pyriform in outline, and occupies the upper part of the abdominal cavity. It measures about 13 inches long, 5 deep, and 3½ wide, and has a capacity of about five pints. It presents two orifices, the cardiac or esophageal and the pyloric; two curvatures, the lesser and the greater.

The left or cardiac end of the stomach is enlarged and forms the fundus; the right end is much narrower and forms the pylorus. The stomach possesses three coats:—

1. The serous or reflection of the peritoneum.
2. The muscular, the fibers of which are arranged in a longitudinal, a circular, and an oblique direction. At the pyloric end the circular fibers increase in number and form a thick ring or band, which is known as the sphincter of the pylorus.

3. The mucous, which is somewhat larger than the muscular coat, and in consequence is thrown into folds or rugæ. The surface of the mucous coat is covered by tall, narrow columnar epithelium.

Gastric Juice.—During the period of time the food remains in the stomach it is subjected to the disintegrating action of an acid fluid, the gastric juice. This fluid, secreted from glands in the mucous membrane, is thoroughly incorporated with the food in consequence of the contractions of the muscular coat. The food is gradually liquefied and reduced to a form which partly fits it for passage into the small intestine, and for absorption into the blood. Gastric juice, when obtained in a pure state, is a clear, colorless fluid, decidedly acid in reaction, with a specific gravity of 1005. It is composed of the following ingredients:—

COMPOSITION OF GASTRIC JUICE.

Water,	994.404
Hydrochloric acid,	0.200
Organic matter (pepsin),	3.195
Inorganic salts,	2.201
	1000.000

The water forms by far the largest part of this fluid, and serves the purpose of holding the other ingredients in solution, and by its saturating power brings them into relation with the constituents of the food. Of the inorganic salts the sodium and potassium chlorids are the most abundant and important.

The *hydrochloric acid*, which exists in a free state, is present in variable amounts. In the above table the amount of parts per thousand is much less than usually stated. According to most observers it is present to the extent of from 0.2 to 0.3 parts per hundred. Though secreted as soon as the food enters the stomach, the acid cannot be detected in the free state until after the lapse of thirty or forty minutes. It acidulates the food and prevents fermentative changes.

The *pepsin* which is present in gastric juice associated with the organic matter is a hydrolytic ferment or enzyme. When freed from its associations and obtained in a pure state, pepsin presents the characteristics of a colloïdal body, and resembles in its reactions the albuminoids. It is capable, when brought into relation with acidulated proteids, of transforming them into new forms capable of absorption into the blood.

Rennin.—In addition to pepsin a second ferment exists in the gastric juice to which the term *rennin* has been given. It possesses the power of coagulating the *caseinogen* of milk. It exists in the mucous membrane,

from which it can be extracted by appropriate means. When rennin acts on caseinogen the latter is split into insoluble *casein* and a soluble albumin. Calcium phosphate is essential to the action of this enzyme.

Gastric Glands.—Imbedded within the mucous membrane are to be found enormous numbers of tubular glands which, though resembling each other in general form, differ in their histologic details in different portions of the stomach.

In the cardiac end or fundus the glands consist of several long tubules

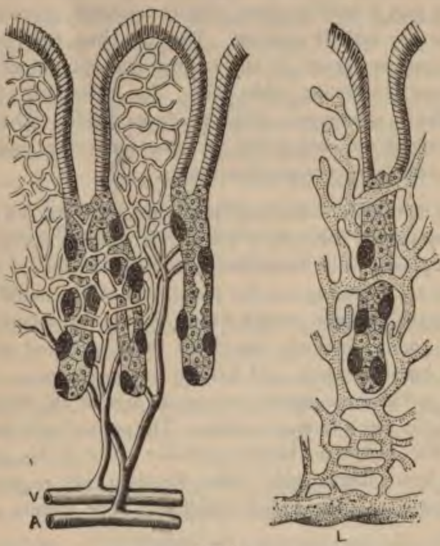

FIG. 8.

Diagram showing the relation of the ultimate twigs of the blood-vessels, V and A, and of the absorbent radicles to the glands of the stomach and the different kinds of epithelium, viz., above cylindrical cells; small, pale cells in the lumen, outside which are the dark ovoid cells.—(*Yeo's Text-Book of Physiology.*)

which open into a short, common duct, which opens by a wide mouth on the surface of the mucous membrane. Each gland consists primarily of a basement membrane lined by epithelial cells. In the duct the epithelium is of the columnar variety, resembling that covering the surface of the mucous membrane. The secretory portion of the tubule is lined by a layer of short, polyhedral, granular and nucleated cells, which, as they border the

lumen of the tubule and thus occupy the central portion of the gland, are termed *central* cells. At irregular intervals, between the central cells and the wall of the tubule, are found large oval reticulated cells, which, on account of their position, are termed *parietal* cells. (See Fig. 8.)

Each parietal cell is in relation with a system of fine canals, which open directly into the lumen of the gland. It is estimated that the fundus contains about five million glands. In the pyloric end of the stomach, the glands are generally branched at their lower extremities, and the common duct is long and wide. The duct is lined by columnar epithelium, while the secreting part is lined by short, slightly columnar, granular cells. The parietal cells are entirely wanting. The epithelium covering the surface of the mucous membrane is tall, narrow, and cylindrical in shape, and consists of mucus-secreting goblet cells. The outer half of the cell contains a substance, mucinogen, which produces mucin. The gastric glands in both situations are surrounded by a fine connective tissue, which supports blood-vessels, nerves, and lymphatics.

Changes in the Cells During Secretion.—During the periods of rest and secretory activity the cells of the glands undergo changes in structure which are supposed to be connected with the production of the pepsin and hydrochloric acid. During rest, the protoplasm of the central cells becomes filled with granular matter, which during the time of secretion disappears, presumably passing into the lumen of the tubule, and as a result the protoplasm becomes clear and hyaline in appearance. The granular material is probably the mother substance, *pepsinogen*, which, inactive in itself, yields the active ferment, pepsin. The parietal cells during digestion increase in size, but do not become granular. It is at this period that they secrete the hydrochloric acid. After digestion they rapidly diminish in size and return to their former condition. The pyloric glands secrete pepsin only.

Mechanism of Secretion.—In the intervals of digestion the mucous membrane of the stomach is covered with a layer of mucus. As soon as the food passes from the esophagus into the stomach, the blood-vessels dilate, the circulation becomes more active, and the membrane assumes a bright red appearance. Coincidently, small drops of gastric juice begin to exude from the glands, which, as they increase in quantity, run together and trickle down the sides of the stomach. This pouring out of fluid continues during the presence of food in the stomach.

The secretion of gastric juice is a reflex act, taking place through the central nervous system and called forth in response to the stimulus of food

in the stomach. That the central nervous system also directly influences the production of the secretion is shown by the fact that mental emotion, such as fear and anger, will arrest or vitiate the normal secretion. The reflex nature of the process can be shown by experimentation upon the pneumogastric nerve. If during digestion, when the peristaltic movements are active and the gastric mucous membrane flushed and covered with gastric juice, the pneumogastric nerves are divided on both sides, the mucous membrane becomes pale, the secretion is arrested, and the peristaltic movements become less marked. Stimulation of the peripheral end produces no constant effects; stimulation of the central end, however, is at once followed by dilatation of the vessels, flushing of the mucous membrane, and a re-establishment of the secretion. It is evident, therefore, that during digestion afferent impulses are passing up the pneumogastrics to the medulla; efferent impulses, in all probability, pass through the fibers of the sympathetic nervous system to the blood-vessels and glands concerned in the elaboration of the gastric juice. After all the nervous connections of the stomach are divided, a small quantity of juice continues to be secreted for several days. This has been attributed to the action of a local nervous mechanism and to the direct action of the food upon the protoplasm of the secreting cells.

Chemic Action of the Gastric Juice.—By the combined influence of the contraction of the muscular walls, the action of the gastric juice, and the temperature, the food is reduced to a semiliquid condition and acquires a distinct acid odor. This semifluid mass will vary in composition and appearance according to the nature of the food. To this matter the term *chyme* has been given.

Meat is rapidly disintegrated by the solution of the connective tissue. The fibers thus separated are readily broken up into particles by solution of the sarcolemma. Well-cooked meat is more easily digested owing to the conversion of the connective tissue into gelatin.

Connective tissues in the raw or imperfectly gelatinized condition are very slowly dissolved. Cartilage, tendons, and even bones, will in time be corroded and liquefied.

Vegetables are not easily digested unless thoroughly prepared by sufficient cooking. The nutritive principles are enclosed by cellulose walls which are not affected by gastric juice. The influence of heat and moisture softens and ruptures the cellulose walls so as to permit the introduction of gastric juice and the solution of its nutritive principles.

The principal action of the gastric juice, however, is to transform the

different proteid principles of the food into *peptones*, the intermediate stages of which are due to the influence of the acid and pepsin respectively. As soon as any one of the albumins is penetrated by the acid it is converted into *acid-albumin* or *parapeptone*. In a short time this product, under the influence of the pepsin, changes into a somewhat different compound termed *albumose*, of which there are probably several varieties. The final stage is that of *peptone*, the form under which the proteids finally are absorbed.

The albumin molecule, moreover, is composed of two distinct portions, which may be termed, respectively, *hemi-* and *anti-*. In the process of digestion the molecule divides into these portions, each of which passes through practically the same changes, as shown by the following table:—

ALBUMIN.	
Hemi-albumin	Anti-albumin
Hemi-albumose	Anti-albumose
Hemipeptone	Antipeptone

The hemipeptone differs from the antipeptone in the fact that it is capable of decomposition into leucin and tyrosin by the action of the pancreatic juice.

Peptones.—Peptones are the final products of the digestion of proteid bodies, and differ from the bodies from which they are derived by the following particulars:—

1. They are *diffusible; i. e.*, capable of passing readily through animal membranes, a condition essential for their absorption.
2. They are *soluble* in water and saline solution.
3. They are *noncoagulable* by heat, nitric or acetic acids. They can be readily precipitated, however, by tannic acid, bile acids, and by mercuric chlorid.
4. They are *absorbable* and *assimilable* by the blood, and by it transformed into serum-albumin.

The duration of gastric digestion will depend largely upon the quantity and quality of the food. The average meal occupies from three to five hours.

Movements of the Stomach.—As soon as digestion commences the cardiac and pyloric orifices are closed; the walls of the stomach contract

upon the food, and a peristaltic action begins, which carries the food along the greater and lesser curvatures, and thoroughly incorporates it with the gastric juice. As soon as any portion of the food is digested it passes through the pylorus into the intestine.

TABLE SHOWING DIGESTIBILITY OF VARIOUS ARTICLES OF FOOD.

	Hours.	*Minutes.*
Eggs, whipped,	1	20
" soft boiled,	3	..
" hard boiled,	3	30
Oysters, raw,	2	55
" stewed,	3	30
Lamb, broiled,	2	30
Veal, broiled,	4	..
Pork, roasted,	5	15
Beefsteak, broiled,	3	..
Turkey, roasted,	2	25
Chicken, boiled,	4	..
" fricasseed,	2	45
Duck, roasted,	4	..
Soup, barley, boiled,	1	30
" bean, "	3	..
" chicken, "	3	..
" mutton, "	3	30
Liver, beef, broiled,	2	..
Sausage, "	3	20
Green corn, boiled,	3	45
Beans, "	2	30
Potatoes, roasted,	2	30
" boiled,	3	30
Cabbage, "	4	30
Turnips, "	3	30
Beets, "	3	45
Parsnips, "	2	30

INTESTINAL DIGESTION.

The process of digestion as it takes place in the small intestine is exceedingly important and complex, and is brought about by the action of the pancreatic juice, the bile, and the intestinal juice.

The contents of the stomach at the close of gastric digestion consist of water, inorganic salts, peptones, undigested albumins and starches, maltose, cane-sugar, liquefied fats, cellulose, and the indigestible portions of meats, cereals, fruits, etc. This so-called chyme is quite acid in reaction, and upon its passage through the now open pylorus into the intestine it excites a reflex stimulation and secretion of the intestinal fluids, which are decidedly

alkaline in reaction, and which have neutralizing action on the chyme. As soon as the latter becomes alkaline and gastric digestion arrested, the various phases of intestinal digestion begin which eventuate in the transformation of all the remaining undigested nutritive materials into absorbable and assimilable compounds.

The Small Intestine is about 22 feet in length and about 1½ inches in diameter. Like the stomach, it possesses three coats, as follows:—

1. The *serous*, or peritoneal.
2. The *muscular*, the fibers of which are arranged for the most part circularly. Some of the fibers are so arranged as to form longitudinal bands.
3. *Mucous*, which presents a series of transverse folds known as the *valvulæ conniventes*.

Intestinal Glands.—In that portion of the small intestine known as the duodenum, are to be found a number of small branched tubular glands (Brunner's), the acini of which are lined by short cylindrical cells, similar to those lining the pyloric glands. From the duodenum to the termination of the intestine the mucous membrane contains an enormous number of tubular glands (Lieberkühn's) formed by an inversion of the basement membrane and lined by epithelial cells. The common secretion of these intestinal glands forms the intestinal juice. This is a thin, opalescent, slightly yellow fluid, alkaline in reaction, and contains water, salts, and proteid matter.

The *function* of the intestinal juice is but incompletely known. It appears to have the power of converting starch into dextrose; it is doubtful if it is capable of digesting either albumins or fats. Its most distinctive action is the inversion of cane-sugar, maltose, and lactose into dextrose, and thus preparing them for absorption. This change is dependent on the presence of a ferment body known as *invertin*.

The Pancreatic Juice is secreted by the pancreas, a flattened gland about six inches long, running transversely across the posterior wall of the abdomen behind the stomach; its duct opens into the duodenum.

The pancreas is similar in structure to the salivary glands, consisting of a system of ducts terminating in acini. The acini are tubular or flask-shaped, and consist of a basement membrane lined by a layer of cylindrical, conical cells, which encroach upon the lumen of the acini. The cells exhibit a difference in their structure (Fig. 9), and may be said to consist of two zones, viz., an *outer parietal zone*, which is transparent and apparently homogeneous, staining rapidly with carmin; an *inner zone*, which

borders the lumen, and is distinctly granular and stains but slightly with carmin. These cells undergo changes similar to those exhibited by the cells of the salivary glands during and after active secretion. As soon as the secretory activity of the pancreas is established, the granules disappear, and the inner granular layer becomes reduced to a very narrow border, while the outer zone increases in size and occupies nearly the entire cell. During the intervals of secretion, however, the granular layer reappears and increases in size until the outer zone is reduced to a minimum. It would seem that the granular matter is formed by the nutritive processes occurring in the gland during rest, and is discharged during secretory activity into the ducts, and takes part in the formation of the pancreatic secretion.

The pancreatic juice is transparent, colorless, strongly alkaline, and viscid,

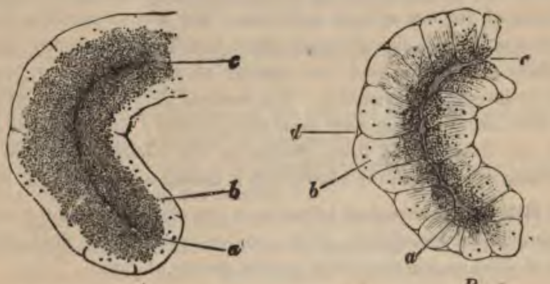

FIG. 9.—ONE SACCULE OF THE PANCREAS OF THE RABBIT IN DIFFERENT STATES OF ACTIVITY.

A. After a period of rest, in which case the outlines of the cells are indistinct, and the inner zone, *i e.*, the part of the cells (*a*) next the lumen (*c*), is broad and filled with fine granules. *B*. After the gland has poured out its secretion, when the cell outlines (*d*) are clearer, the granular zone (*a*) is smaller, and the clear outer zone is wider.—(*Yeo's Text-Book of Physiology, after Kühne and Lea.*)

and has a specific gravity of 1.040. It is one of the most important of the digestive fluids, as it exerts a transforming influence upon all classes of alimentary principles, and has been shown to contain at least three distinct ferments. It has the following composition:—

COMPOSITION OF PANCREATIC JUICE.

Water,	900.76
Albuminoid substances,	90.44
Inorganic salts,	8.80
	1000.00

The pancreatic juice is characterized by its action:—

1. Upon *starch*. When starch is subjected to the action of the juice it is at once transformed into maltose; the change takes place more rapidly than when saliva is added. This action is caused by the presence of a special ferment, *amylopsin*.
2. Upon *albumin*. The albuminous bodies are changed by the juice into, first, an alkali albumin, then into albumose, and ultimately into true peptone. As in the case of gastric digestion, the albumin molecule is divided into a *hemi* and an *anti* half. The albumin does not swell up, as is the case in gastric digestion, but is gradually corroded and dissolved. This change is due to the presence of the ferment, *trypsin*. Long-continued action of trypsin converts the *hemi* peptones into two crystalline bodies, leucin and tyrosin.
3. Upon *fats*. The most striking action of the pancreatic juice is the *emulsification* of the fats or their subdivision into minute particles of microscopic size. This change takes place rapidly and depends upon the alkalinity of the fluid and the quantity of albumin present, combined with the intestinal movements. The *neutral fats* are also decomposed into their corresponding *fatty acids* and *glycerin*; the acids thus set free unite with the alkaline bases present in the intestine and form soaps. This decomposition of the neutral fats is caused by the ferment, *steapsin*.

The Bile has an important influence in the elaboration of the food and its preparation for absorption. It is a golden-brown, viscid fluid, having a neutral or alkaline reaction and a specific gravity of 1.020.

COMPOSITION OF BILE.

Water,	859.2
Sodium glycocholate, Sodium taurocholate,	91.4
Fat,	9.2
Cholesterin,	2.6
Mucus and coloring matter,	29.8
Salts,	7.8
	1000.00

The *biliary salts*, sodium glycocholate and taurocholate, are characteristic ingredients, and are formed in the liver by the process of secretion from materials furnished by the blood. It is probable that they are derived from the nitrogenized compounds, though the stages in the process are unknown. They are reabsorbed from the small intestine to play some ulterior part in nutrition.

Cholesterin is a product of waste taken up by the blood from the nervous tissues and excreted by the liver. It crystallizes in the form of rhombic plates, which are quite transparent. When retained within the blood, it gives rise to the condition of *cholesteremia*, attended with severe nervous symptoms. It is given off in the feces under the form of stercorin.

The *coloring matters* which give the tints to the bile are *biliverdin* and *bilirubin*, and are probably derived from the coloring matter of the blood. Their presence in any fluid can be recognized by adding to it nitric acid containing nitrous acid, when a play of colors is observed, beginning with green, blue, violet, red, and yellow.

The Bile is both a secretion and an excretion; it is constantly being formed and discharged by the hepatic ducts into the gall bladder, in which it is stored up during the intervals of digestion. As soon as food enters the intestines it is poured out abundantly by the contraction of the walls of the gall bladder.

The *amount* secreted in twenty-four hours is about 2½ pounds.

Functions of the Bile.—

1. It assists in the *emulsification* of the fats and promotes their absorption.
2. It tends to prevent putrefactive changes in the food.
3. It stimulates the secretion of the intestinal glands, and excites the normal peristaltic movement of the bowels.

The digested food, the *chyme*, is a grayish, pultaceous mass, but as it passes through the intestines it becomes yellow from admixture with the bile. It is propelled onward by vermicular motion—by the contraction of the circular and longitudinal muscular fibers.

During the passage of the digesting food through the intestinal canal the nutritive products, the peptones, the dextrose and levulose, the fatty emulsions, the fatty acids and their soaps, are absorbed into the blood, while the undigested residue is carried onward by the peristaltic movements through the iliocecal valve into the large intestine.

Intestinal Fermentation.—Owing to the favorable conditions for fermentative and putrefactive processes—*e. g.*, heat, moisture, oxygen, micro-organisms—the food when consumed in excessive quantity, or when acted on by defective secretions, undergoes a series of decomposition changes which are attended by the production of gases and various chemic compounds. Grape sugar and maltose are partially split into lactic acid, this into butyric acid, carbon dioxid, and hydrogen. Fats are reduced to glycerol and fatty acids; the glycerol, according to the organisms present, yields succinic and other fatty acids, carbon dioxid, and hydrogen.

The proteids, under the prolonged action of the pancreatic juice, are decomposed, and yield leucin and tyrosin; the former is split into valerianic acid, ammonia, and carbon dioxid; the latter is split into indol, which is the antecedent of indican in the urine. Skatol is another proteid derivative constantly present in the fecal substance.

The Large Intestine extends from the iliocecal valve to the anus, and measures about five feet in length. It also consists of the three coats: the serous, the muscular, and mucous. The mucous membrane contains a number of mucous glands, the secretion from which lubricates the surface of the canal. The ascending portion of the large intestine possesses the power of absorption, and hence its contents become less liquid and more consistent. As the residue passes toward the sigmoid flexure it acquires the characteristic of the fecal matter. This consists of the undigested portions of the food, decomposition products, mucus, and inorganic salts.

Defecation is the voluntary act of extruding the feces from the rectum, and is accomplished by a relaxation of the sphincter ani muscle, the contraction of the muscular walls of the rectum, aided by the contraction of the abdominal muscles.

ABSORPTION.

The term absorption is applied to the passage or transference of material into the blood from the tissues, from the serous cavities, and from the mucous surfaces of the body. The most important of these surfaces, especially in its relation to the formation of the blood, is the mucous surface of the alimentary canal; for it is from this organ that new materials are derived which maintain the quality and quantity of the blood. The absorption of materials from the interstices of the tissues is to be regarded rather as a return to the blood of liquid nutritive material which has escaped from the blood-vessels for nutritive purposes, and which, if not returned, would lead to an accumulation of such fluid and the development of dropsical conditions.

The anatomic mechanisms involved in the absorptive process are, primarily, the *lymph spaces*, the *lymph capillaries* and *blood capillaries*; secondarily, the *lymphatic vessels* and *larger blood-vessels*.

Lymph Spaces, Lymph Capillaries, Blood Capillaries.—Everywhere throughout the body, in the intervals of connective tissue bundles, and in the interstices of the several structures of which an organ is composed, are found spaces of irregular shape and size, determined largely by

the nature of the organ in which they are found, which have been termed *lymph spaces* or *lacunæ*, from the fact that during the living condition they are continually receiving the lymph which has escaped from the blood-vessels throughout the body. In addition to the connective tissue lymph spaces, various observers have described special lymph spaces in the testicle, kidney, liver, thymus gland, and spleen; in all secreting glands between the basement membrane and blood-vessels; around blood-vessels (perivascular spaces), and around nerves. The *serous cavities* of the body, peritoneal, pleural, pericardial, etc., may also be regarded as lymph spaces, which are in direct communication by open mouths or *stomata* with the lymphatic capillaries. This method of communication is not only true of serous membranes, but to some extent also of mucous membranes. The cylindrical sheaths and endothelial cells surrounding the brain, spinal cord, and nerves can also be looked upon as lymph spaces in connection with lymph capillaries.

The *lymphatic capillaries*, in which the lymphatic vessels proper take their origin, are arranged in the form of plexuses of quite irregular shape. In most situations they are intimately interwoven with the blood-vessels, from which, however, they can be readily distinguished by their larger caliber and irregular expansions. The wall of the lymph capillary is formed by a single layer of epithelioid cells, with sinuous outlines, and which accurately dovetail with each other. In no instance are valves found. In the villus of the small intestine the beginning of the lacteal is to be regarded as a lymph capillary, generally club-shaped, which at the base of the villus enters a true lymphatic; at this point a valve is present, which prevents regurgitation. The lymphatic capillaries anastomose freely with each other, and communicate on the one hand with the lymph spaces, and on the other with the lymphatic vessels proper.

As the shape, size, etc., of both lymph spaces and capillaries are determined largely by the nature of the tissues in which they are contained, it is not always possible to separate the one from the other. Their function, however, may be regarded as similar, viz.: the collection of the lymph which has escaped from the blood-vessels, and its transmission onward into the regular lymphatic vessels.

The *blood capillaries* not only permit the escape of the liquid nutritive portions of the blood through their delicate walls, but are also engaged in the reabsorption of this transudate as well as in the absorption of new materials from the alimentary canal. The extensive capillary network which is formed by the ultimate subdivision of the arterioles in the submucous tissue and villi of the small intestine forms an anatomic arrange-

ment well adapted for absorption. It is now well known that in the absorption of the products of digestion the blood capillaries are more active than the lymphatic capillaries.

Lymphatic Vessels.—The lymphatic vessels constitute a system of minute, delicate, transparent vessels, found in nearly all the organs and tissues of the body. Having their origin at the periphery in the lymphatic capillaries and spaces, they gradually converge toward the trunk of the body and empty into the thoracic duct. In their course they pass through numerous small ovoid bodies, the lymphatic glands.

The lymphatic vessels of the small intestine (*the lacteals*) arise within the villous processes which project from the inner surface of the intestine throughout its entire extent. The wall of the villus is formed by an elevation of the basement membrane, and is covered by a layer of columnar epithelial cells. The basis of the villus consists of adenoid tissue, fine plexus of blood-vessels, unstriped muscular fibers, and the lacteal vessel. The adenoid tissue consists of a number of intercommunicating spaces, containing leukocytes. The lacteal vessel possesses a thin but distinct wall composed of endothelial plates, with here and there openings which bring the interior of the villus into communication with the spaces of the adenoid tissue.

The *structure* of the larger vessels resembles that of the veins, consisting of three coats:—

1. *External*, composed of fibrous tissue and muscular fibers, arranged longitudinally.
2. *Middle*, consisting of white fibers and yellow elastic tissue, nonstriated muscular fibers, arranged transversely.
3. *Internal*, composed of an elastic membrane, lined by endothelial cells.

Throughout their course are found numerous *semilunar valves*, looking toward the larger vessels, formed by a folding of the inner coat and strengthened by connective tissue.

Lymphatic Glands.—The lymphatic glands consist of an external capsule composed of fibrous tissue which contains non-striped muscular fibers; from its inner surface septa of fibrous tissue pass inward and subdivide the gland substance into a series of compartments which communicate with each other. The blood-vessels which penetrate the gland are surrounded by fine threads, forming a follicular arrangement, the meshes of which contain numerous lymph corpuscles. Between the follicular threads and the wall of the gland lies a lymph channel traversed by a reticulum of adenoid tissue. The lymphatic vessels after penetrating this capsule pour their lymph into this channel, through which it passes; it is then collected

by the efferent vessels and transmitted onward. The lymph corpuscles which are washed out of the gland into the lymph stream are formed, most probably, by division of pre-existing cells.

The Thoracic Duct is the general trunk of the lymphatic system into which the vessels of the lower extremities, of the abdominal organs, of the left side of the head, and left arm empty their contents. It is about 20 inches in length, arises in the abdomen, opposite the third lumbar vertebra, by a dilatation, the *receptaculum chyli;* ascends along the vertebral column to the seventh cervical vertebra, and terminates in the venous system at the junction of the internal jugular and subclavian veins on the left side. The lymphatics of the right side of the head, of the right arm, and the right side of the thorax terminate in the *right thoracic duct*, about one inch in length, which joins the venous system at the junction of the internal jugular and subclavian on the right side.

The general arrangement of the lymphatic vessels in shown in Fig. 10.

The Blood-vessels which are concerned in the conduction of fresh nutritive material from the alimentary canal have their origin in the elaborate capillary network in the mucous membrane. The small veins which emerge from the network gradually unite, forming larger and larger trunks, which are known as the gastric, superior, and inferior mesenteric veins. These finally unite to form the portal vein, a short trunk about three inches in length. The portal vein enters the liver at the transverse fissure, after which it forms a fine capillary plexus ramifying throughout the substance of the liver; from this plexus the hepatic veins take their origin, which finally empty the blood into the vena cava inferior. (See Fig. 11.)

Absorption of Food.—Physiologic experiments have demonstrated that the agents concerned in the absorption of new materials from the alimentary canal are:—

1. The *blood-vessels* of the entire canal, but more particularly those uniting to form the portal vein.
2. The *lymphatics* coming from the small intestine, which converge to empty into the thoracic duct.

As a result of the action of the digestive fluids upon the different classes of food stuffs, albumins, sugars, starches, and fats, there are formed *peptones*, *glucose*, and *fatty emulsion*, which differ from the former in being highly diffusible, a condition essential to their absorption. In order that these substances may get into the blood, they must pass through the layer of cylindrical epithelial cells and the underlying basement membrane, and into the lymph spaces of the villi and submucous tissue. The mechanism

FIG. 10.—DIAGRAM SHOWING THE COURSE OF THE MAIN TRUNKS OF THE ABSORBENT SYSTEM.

The lymphatics of lower extremities (D) meet the lacteals of intestines (LAC) at the receptaculum chyli (RC), where the thoracic duct begins. The superficial vessels are shown in the diagram on the right arm and leg (S), and the deeper ones on the arm to the left (D). The glands are here and there shown in groups. The small right duct opens into the veins on the right side. The thoracic duct opens into the union of the great veins of the left side of the neck (T).—(*Yeo's Text-book of Physiology.*)

by which the cells effect this passage of the food is but imperfectly understood. Osmosis and filtration are conditions, however, made use of by the cells in the absorptive process.

The products of digestion find their way into the general circulation by two routes :—

1. The *water*, *peptones*, *glucose*, and *soluble salts*, after passing into the lymph spaces of the villi, pass through the wall of the capillary blood-

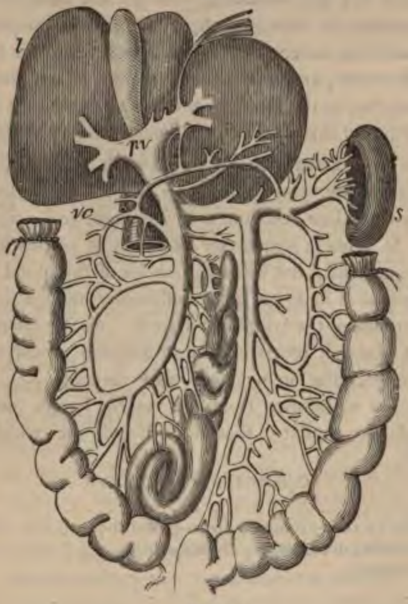

FIG. 11.

Diagram of the portal vein (*pv*) arising in the alimentary tract and spleen (*s*), and carrying the blood from these organs to the liver.—(*Yeo's Text-Book of Physiology.*)

vessel; entering the blood, they are carried to the liver by the vessels uniting to form the portal vein; emerging from the liver, they are emptied into the inferior vena cava by the hepatic vein.

2. The *emulsified fat* enters the lymph capillary in the interior of the villus; by the contraction of the layer of muscular fibers surrounding it its contents are forced onward into the lymphatic vessel or *lacteal*,

thence into the thoracic duct, and finally into the circulation at the junction of the internal jugular and subclavian veins on the left side.

Absorption of Lymph.—Similar to the absorption of food from the alimentary canal is the absorption of lymph from the lymph spaces of the organs and tissues. During the passage of the blood through the capillary blood-vessels, a portion of the liquor sanguinis or plasma or lymph passes through the capillary wall out into the lymph spaces. The tissue cells are thus bathed with this new material; from it those substances are selected which are necessary for their growth, repair, and all purposes of nutrition. An excess of nutritive material, far beyond the needs of the tissues, transudes from the blood-vessels, and it is this excess which is absorbed by the lymphatics and returned to the blood by the thoracic duct. It is quite probable also that a portion of this transudate is reabsorbed by the blood-vessels.

Properties and Composition of Lymph and Chyle.—Lymph, as found in the lymphatic vessels of animals, is a clear, colorless, or opalescent fluid, having an alkaline reaction, a saline taste, and a specific gravity of about 1.040. It holds in suspension a number of corpuscles resembling in their general appearance the white corpuscles of the blood. Their number has been estimated at 8200 per cubic millimeter, though the number varies in different portions of the lymphatic system. As the lymph flows through the lymphatic gland it receives a large addition of corpuscles. Lymph corpuscles are granular in structure, and measure $\frac{1}{2500}$ of an inch in diameter. When withdrawn from the vessels, lymph undergoes a spontaneous coagulation, similar to that of the blood, after which it separates in serum and clot.

COMPOSITION OF LYMPH.

Water,	96.536
Proteids (serum-albumin, fibrin-globulin),	1.320
Extractives (urea, sugar, cholesterin),	1.559
Fatty matters,	a trace.
Salts,	0.585
	100.000

Chyle.—Chyle is the fluid found in the lymphatic vessels, coming from the small intestine after the digestion of a meal containing fat. In the intervals of digestion, the fluid of these lymphatics is identical in all respects with the lymph found in all other regions of the body. As soon as the emulsified fat passes into the lymphatic vessels and mingles with the lymph it becomes milky in color, and the vessels which previously were invisible become visible, and resemble white threads running between the layers of the mesentery. Chyle has a composition similar to that of lymph,

but it contains, in addition, numerous fatty granules, each surrounded by an albuminous envelope. When examined microscopically the chyle presents a fine molecular basis, made up of the finely divided granules of fat.

COMPOSITION OF CHYLE.

Water,	902.37
Albumin,	35.16
Fibrin,	3.70
Extractives,	15.65
Fatty matters,	36.01
Salts,	7.11
	1000.00

Forces Aiding the Movement of Lymph and Chyle.—The lymph and chyle are continually moving in a progressive manner from the periphery or beginning of the lymphatic system to the final termination of the thoracic duct. The force which primarily determines the movement of the lymph has its origin in the beginnings of the lymphatic vessels, and depends upon the difference in pressure here and the pressure in the thoracic duct. The greater the quantity of fluid poured into the lymph spaces the greater will be the pressure and consequently the movement. The first movement of chyle is the result of a contraction of the muscular fibers within the walls of the villus. At the time of contraction, the lymphatic capillary is compressed and shortened, and its contents forced onward into the true lymphatic. When the muscular fibers relax, regurgitation is prevented by the closure of the valve in the lymphatic at the base of the villus.

As the walls of the lymphatic vessels contain muscular fibers, when they become distended these fibers contract and assist materially in the onward movement of the fluid.

The contraction of the general muscular masses in all parts of the body, by exerting an intermittent pressure upon the lymphatics, also hastens the current onward; regurgitation is prevented by the closure of valves which everywhere line the interior of the vessels.

The respiratory movements aid the general flow of both lymph and chyle from the thoracic duct into the venous blood. During the time of an inspiratory movement the pressure within the thorax, but outside the lungs, undergoes a diminution in proportion to the extent of the movement; as a result, the fluid in the thoracic duct outside of the thorax, being under a higher pressure, flows more rapidly into the venous system. At the time of an expiration, the pressure rises and the flow is temporarily impeded, only to begin again at the next inspiration.

BLOOD.

The **Blood** is a nutritive fluid containing all the elements necessary for the repair of the tissues; it also contains principles of waste absorbed from the tissues, which are conveyed to the various excretory organs and by them eliminated from the body.

The *total amount* of blood in the body is estimated to be about one-eighth of the body weight; from 16 to 18 pounds in an individual of average physical development. The quantity varies during the twenty-four hours, the *maximum* being reached in the afternoon, the *minimum* in the early morning hours.

Blood is a heterogeneous, opaque, red fluid, having an alkaline reaction, a saline taste, and a specific gravity of 1.055.

The *opacity* is due to the refraction of the rays of light by the elements of which the blood is composed. The *color* varies in hue, from a bright scarlet in the arteries to a deep purple in the veins, due to the presence of a coloring matter, *hemoglobin*, in different degrees of oxidation.

The *alkalinity* is constant, and depends upon the presence of the alkaline sodium phosphate, Na_2HPO_4.

The *saline taste* is due to the amount of sodium chlorid present.

The *specific gravity* ranges within the limits of health from 1.045 to 1.075.

The *odor* of the blood is characteristic, and varies with the animal from which it is drawn, due to the presence of caproic acid.

The *temperature* of the blood ranges from 98° F. at the surface to 107° F. in the hepatic vein; it loses heat by radiation and evaporation as it approaches the extremities and as it passes through the lungs.

Blood Consists of Two Portions:—

1. The *liquor sanguinis* or *plasma*, a transparent, colorless fluid, in which are floating—
2. *Red and white corpuscles;* these constituting by weight less than one-half, 40 per cent., of the entire amount of blood.

COMPOSITION OF PLASMA.	*Dalton.*
Water,	902.00
Albumin,	53.00
Paraglobulin,	22.00
Fibrinogen,	3.00
Fatty matters,	2.50
Crystallizable nitrogenous matters,	4.00
Other organic matter,	5.00
Mineral salts,	8.50
	1000.00

Water acts as a solvent for the inorganic matters and holds in suspension the corpuscular elements.

Albumin is the nutritious principle of the blood; it is absorbed by the tissues to repair their waste and is transformed into the organic basis characteristic of each structure.

Paraglobin or *fibrinoplastin* is a soft, amorphous substance precipitated by sodium chlorid in excess, or by passing a stream of carbonic acid through dilute serum.

Fibrinogen can also be obtained by *strongly diluting* the serum and passing carbonic acid through it for a long time, when it is precipitated as a viscous deposit.

Fatty matter exists in small proportion, except in pathologic conditions and after the ingestion of food rich in oleaginous matters; it soon disappears, undergoing oxidation, generating heat and force, or is deposited as adipose tissue.

Sugar is represented by glucose, a product of the digestion of saccharin matter and starches in the alimentary canal; glycogenic matter is derived from the liver.

The *saline constituents* aid the process of osmosis, give alkalinity to the blood, promote the absorption of carbonic acid from the tissues into the blood, and hold other substances in solution; the most important are the sodium and potassium chlorids, the calcium and magnesium phosphates.

Excrementitious matters are represented by carbonic acid, urea, creatin, creatinin, urates, oxalates, etc.; they are absorbed from the tissues by the blood and conveyed to the excretory organs, lungs, kidneys, etc.

Gases.—Oxygen, nitrogen, and carbonic acid exist in varying proportions.

BLOOD CORPUSCLES.

The corpuscular elements of the blood occur under two distinct forms, which, from their color, are known as the *red* and *white* corpuscles.

The *red corpuscles* as they float in a thin layer of the liquid sanguinis are of a pale straw color; it is only when aggregated in masses that they assume the bright red color. In form they are circular and biconcave; they have an average diameter of the $\frac{1}{3200}$ths of an inch.

In mammals, birds, reptiles, amphibia, and fish the corpuscles vary in size and number, gradually becoming larger and less numerous as the scale of animal life is descended, *e. g.* :—

TABLE SHOWING COMPARATIVE DIAMETER OF RED CORPUSCLES.

Mammals.		*Birds.*		*Reptiles.*		*Amphibia.*		*Fish.*	
Man,	$\frac{1}{3200}$	Eagle,	$\frac{1}{1812}$	Turtle,	$\frac{1}{1231}$	Frog,	$\frac{1}{1108}$	Perch,	$\frac{1}{2099}$
Chimpanzee,	$\frac{1}{3412}$	Owl,	$\frac{1}{1783}$	Tortoise,	$\frac{1}{1252}$	Toad,	$\frac{1}{1043}$	Carp,	$\frac{1}{2142}$
Ourang,	$\frac{1}{3383}$	Sparrow,	$\frac{1}{2140}$	Lizard,	$\frac{1}{1555}$	Proteus,	$\frac{1}{400}$	Pike,	$\frac{1}{2000}$
Dog,	$\frac{1}{3542}$	Swallow,	$\frac{1}{2133}$	Viper,	$\frac{1}{1274}$	Siren,	$\frac{1}{420}$	Eel,	$\frac{1}{1745}$
Cat,	$\frac{1}{4404}$	Pigeon,	$\frac{1}{1973}$			Amphiuma,	$\frac{1}{363}$		
Hog,	$\frac{1}{4230}$	Turkey,	$\frac{1}{2045}$						
Horse,	$\frac{1}{4600}$	Goose,	$\frac{1}{1858}$						
Ox,	$\frac{1}{4267}$	Swan,	$\frac{1}{1808}$						

In man and the mammals the red corpuscles present neither a nucleus nor a cell wall, and are universally of a small size. They can be readily distinguished from the corpuscles of birds, reptiles, and fish, in which they are larger, oval in shape, and possess a well-defined nucleus.

The red corpuscles are exceedingly numerous, amounting to about 5,000,000 in a cubic millimeter of blood. In structure they consist of a firm, elastic, colorless framework, the *stroma*, in the meshes of which is entangled the coloring matter, the *hemoglobin*.

CHEMIC COMPOSITION OF RED CORPUSCLES.

Water,	688.00
Globulin,	282.22
Hemoglobin,	16.75
Fatty matter,	2.31
Extractives,	2.60
Mineral salts,	8.12
	1000.00

Hemoglobin, the coloring matter of the corpuscles, is an albuminous compound, composed of C. O. H. N. S. and iron. It may exist either in an amorphous or crystalline form. When deprived of all its oxygen, except the quantity entering into its intimate composition, the hemoglobin becomes dark in color, somewhat purple in hue, and is known as *reduced hemoglobin*. When exposed to the action of oxygen it again absorbs a definite amount and becomes scarlet in color, and is known as *oxy-hemoglobin*. The amount of oxygen absorbed is 1.76 c.c. ($\frac{7}{10}$ cubic inch) for one milligram ($\frac{1}{64}$ grain) of hemoglobin.

It is this substance which gives the color to the venous and arterial blood. As the venous blood passes through the capillaries of the lungs, the *reduced hemoglobin* absorbs the oxygen from the pulmonary air and becomes *oxy-hemoglobin*, scarlet in color, and the blood becomes arterial. When the arterial blood passes into the systemic capillaries, the oxygen is

absorbed by the tissues, the hemoglobin becomes reduced, purple in color, and the blood becomes venous. A dilute solution of oxy-hemoglobin gives two absorption bands between the lines D and E of the solar spectrum. Reduced hemoglobin gives but one absorption band, occupying the space existing between the two bands of the oxy-hemoglobin spectrum.

The *function* of the red corpuscle is, therefore, to absorb oxygen and carry it to the tissues; the smaller the corpuscles and the greater the number, the greater is the quantity of oxygen absorbed; and, consequently, all the vital functions of the body become more active.

The *white corpuscles* are far less numerous than the red, the proportion being, on an average, about one white to 350 or 400 red; they are globular in shape, and measure the $\frac{1}{2500}$ths of an inch in diameter, and consist of a soft, granular, colorless substance, containing several nuclei.

The *white corpuscles* possess the power of spontaneous movement, alternately contracting and expanding, throwing out processes of their substance and quickly withdrawing them, thus changing their shape from moment to moment. These movements resemble those of the ameba, and for this reason are termed *ameboid*. They also possess the capability of moving from place to place. In the interior of the vessels they adhere to the inner surface, while the red corpuscles move through the center of the stream.

The white corpuscles are identical with the leukocytes, and are found in milk, lymph, chyle, and other fluids.

Origin of Corpuscles.—The red corpuscles take their origin from the mesoblastic cells in the vascular area of the developing embryo.

In the adult they are produced from colorless nucleated corpuscles resembling the white corpuscles. The spleen is the organ in which they are finally destroyed.

The white corpuscles originate from the leukocytes of the adenoid tissue, and subsequently give rise to the red corpuscles and partly to new tissues that result from inflammatory action.

COAGULATION OF THE BLOOD.

When blood is withdrawn from the body and allowed to remain at rest, it becomes somewhat thick and viscid in from three to five minutes; this viscidity gradually increases until the entire volume of blood assumes a jelly-like consistence, which occupies from five to fifteen minutes.

As soon as coagulation is completed, a second process begins, which consists in the contraction of the coagulum and the oozing of a clear, straw-colored liquid, the *serum*, which gradually increases in quantity as

the *clot* diminishes in size, by contraction, until the separation is completed, which occupies from twelve to twenty-four hours.

The changes in the blood are as follows:—

Before coagulation.

Living blood.	Liq. Sanguinus or Plasma.	Consisting of	Water. Albumin. Fibrinogen. Salts.
	Corpuscles. Red and white.		

After coagulation.

Dead blood.	Crassamentum. Clot or coagulum.	Containing	Fibrin. Corpuscles.
	Serum.	Containing	Water. Albumin. Salts.

The serum, therefore, differs from the liquor sanguinis in not containing fibrin.

In from twelve to twenty-four hours the upper surface of the clot presents a grayish appearance, the *buffy coat*, which is due to the rapid sinking of the red corpuscles beneath the surface, permitting the fibrin to coagulate without them, which then assumes a grayish-yellow tint. Inasmuch as the white corpuscles possess a lighter specific gravity than the red, they do not sink so rapidly, and becoming entangled in the fibrin, assist in forming the buffy coat. Continued contraction gives a *cupped* appearance to the surface of the clot.

Inflammatory states of the blood produce a marked increase in the buffed and cupped condition, on account of the aggregation of the corpuscles and their tendency to rapid sinking.

Nature of Coagulation.—Coagulated fibrin does not preëxist in the blood, but is formed at the moment blood is withdrawn from the vessels. According to Denis, a liquid substance, *plasmin*, exists in the blood, which, when withdrawn from the circulation, decomposes into *fibrin* and *metalbumin*.

According to Schmidt, fibrin results from the union of *fibrinoplastin* (paraglobulin) and *fibrinogen*, brought about by the presence of a third substance, the fibrin ferment.

According to Hammersten and others, the fibrin obtained from the blood after coagulation comes from the fibrinogen alone, the conversion being brought about by the presence of a ferment substance, paraglobulin in this case having nothing to do with the change. This view is supported by the

fact that the quantity of fibrin obtained from the blood is never greater than the quantity of fibrinogen previously present. The origin of the ferment is obscure, but there is reason to believe that it comes from the injured vascular coats or from the breaking of the white corpuscles.

Conditions Influencing Coagulation.—The process is *retarded* by cold, retention within living vessels, neutral salts in excess, inflammatory conditions of the system, imperfect aeration, exclusion from air, etc.

It is *hastened* by a temperature of 100° F., contact with air, rough surfaces, and rest.

Blood Coagulates in the body after the arrest of the circulation in the course of twelve to twenty-four hours; local arrest of the circulation, from compression or a ligature, will cause coagulation, thus preventing hemorrhages from wounded vessels.

The Composition of the Blood varies in different portions of the body. The *arterial* differs from the *venous*, in being more coagulable, in containing more oxygen and less carbonic acid, in having a bright scarlet color, from the union of oxygen with hemoglobin; the purple hue of venous blood results from the deoxidation of the coloring matter.

The blood of the *portal vein* differs in constitution, according to different stages of the digestive process; during digestion it is richer in water, albuminous matter, and sugar; occasionally it contains fat; corpuscles are diminished, and there is an absence of biliary substances.

The blood of the *hepatic vein* contains a larger proportion of red and white corpuscles; the sugar is augmented, while albumin, fat, and fibrin are diminished.

Pathologic Conditions of the Blood.—

1. *Plethora*—increase in the volume or quantity of blood.
2. *Anemia*—deficiency of red globules with increase of water.
3. *Leukocythemia*—increase of white and diminution of red corpuscles.
4. *Glycohemia*—excess of sugar in the blood.
5. *Uremia*—increase in the amount of urea.
6. *Cholesteremia*—an excess of cholesterin in the blood.
7. *Thrombosis* and *embolism*—clotting of blood in the vessels and dissemination of coagula.
8. *Lipemia*—an excess of fat.
9. *Melanemia*—pigment in the blood.

CIRCULATION OF THE BLOOD.

The Circulatory Apparatus by which the blood is distributed to all portions of the body consists of a central organ, the heart, with which is connected a system of closed vessels known as arteries, capillaries, and veins. Within this system the blood is kept, by the action of the heart, in continual movement, distributing nutritious matter to all portions of the body and carrying waste matters from the tissues to the various eliminating organs.

The heart is a hollow, muscular organ, pyramidal in shape, measuring about 5½ inches in length, about 3½ in breadth, weighing from 10 to 12 ozs. in the male and from 8 to 10 ozs. in the female. Situated in the thoracic cavity, between the lungs, its base is directed upward, backward, and to the right; its apex is directed downward and to the left.

Pericardium.—The heart is surrounded by a closed fibrous membrane called the pericardium. The inner surface of this membrane is lined by a serous membrane, which is also reflected over the surface of the heart; between the two surfaces of the serous membrane is found a small quantity of fluid, the pericardial fluid, which lubricates the surfaces and prevents friction during the movements of the heart. The interior of the heart is also lined by a serous membrane called the *endocardium*.

Cavities of the Heart.—The general cavity of the heart is subdivided by a longitudinal septum into a right and left half; each of these cavities is in turn subdivided by a transverse constriction into two smaller cavities which communicate with each other and are known as the auricles and ventricles, the orifice between the auricle and ventricle being known as the *auriculoventricular orifice*. The heart, therefore, consists of four cavities, a right auricle and ventricle and a left auricle and ventricle.

Into the right auricle the two terminal trunks of the venous system, the *superior and inferior venæ cavæ*, empty the venous blood which has been collected from all parts of the system; from the right ventricle arises the *pulmonary artery*, which, passing into the lungs, distributes the blood to the walls of the air cells of the lungs; into the left auricle empty four *pulmonary veins*, which have collected the blood from the lung capillaries; from the left ventricle springs the *aorta*, the general trunk of the arterial system, whose branches distribute the blood to the entire system.

The Valves of the Heart.—The valves of the heart are formed by a reduplication of the endocardium strengthened by connective tissue. At the auriculoventricular openings on the right and left sides of the heart re-

spectively are found the *tricuspid* and *mitral valves*. The tricuspid valve consists of three, the mitral of two, cusps or segments, which project into the interior of the ventricle when it does not contain blood. At their bases the segments are united so as to form an annular membrane attached to the margin of the orifice. To the free edges of the valves are attached numerous fine threads, the *chordæ tendineæ*, which are the tendons of the small papillary muscles springing from the walls of the ventricles.

The Semilunar Valves.—At the openings of the pulmonary artery and the aorta are found three cup-shaped- or semilunar valves, the free edges of which are directed away from the interior of the heart. The anatomic arrangement of the valves is such that upon their closure regurgitation of the blood is prevented.

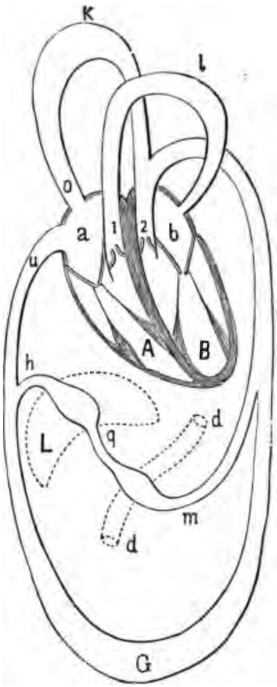

Fig. 12.—Scheme of the Circulation.

a. Right, *b*. left, auricle. A. Right, B. left, ventricle. 1. Pulmonary artery. 2. Aorta. *l*. Area of pulmonary, K. area of systemic, circulation. *o*. The superior vena cava. G. Area supplying the inferior vena cava, *u*. *d*, *d*. Intestine. *m*. Mesenteric artery. *q*. Portal vein. L. Liver. *h*. Hepatic vein.—(*Landois*.)

Movement of the Blood.—The blood within the vascular apparatus is in continual movement from the left side of the heart, through the arterial system, capillaries, and veins, to the right side, and from the right side, through the pulmonary artery, capillaries, and veins, to the original point of departure. The cause of this movement is the difference of pressure which exists between the blood within the aorta and the terminations of the venæ cavæ, and between the blood of the pulmonary artery and the pulmonary veins.

The *function* of the heart is to propel the blood through the blood-vessels, which it does by raising or maintaining this higher pressure in the aorta and pulmonary artery. This is accomplished by alternate contractions and relaxations of its muscular walls. These two movements are known respectively as the *systole* and the *diastole*.

Course of the Blood through the Heart.—The venous blood returned to the heart by the superior and inferior venæ cavæ is emptied during the diastole into the right auricle, in the contraction of which it is forced through the right auriculoventricular opening into the right ventricle and distends it. Upon the contraction of the ventricle the blood is propelled through the pulmonary artery into the lungs, where it undergoes aëration and is changed in color.

The arterial blood is now collected by the pulmonary veins and poured into the left auricle; thence it passes into the left ventricle, which becomes fully distended. Upon the contraction of the ventricle, the blood is propelled into the aorta, and by it distributed to the system at large, to be again returned to the heart by the veins.

Regurgitation from the ventricles into the auricles during the systole is prevented by the closure of the tricuspid and mitral valves; regurgitation from the pulmonary artery and aorta into the ventricles during the diastole is prevented by the closure of the semilunar valves.

While there is but one circulation, physiologists frequently divide the circulatory apparatus into:—

1. The *systemic circulation*, which includes the movement of the blood from the left side of the heart through the aorta and its branches, through the capillaries and veins, to the right side.
2. The *pulmonary circulation*, which includes the course of the blood from the right side through the pulmonary artery, through the capillaries of the lungs and pulmonary veins, to the left side of the heart.
3. The *portal circulation*, which includes the portal vein. This is formed by the union of the radicles of the gastric, mesenteric, and splenic veins, and carries the blood directly into the liver, where the vein again divides into a fine capillary plexus from which the hepatic veins arise which empty into the ascending vena cava.

Movements of the Heart.—At each revolution, during the systole, the heart hardens and becomes shortened in its long diameter; its apex is raised up, rotated on its axis from left to right, and thrown forward against the walls of the chest. The *impulse* of the heart, observed about two inches below the nipple, and one inch to the sternal side, between the fifth and sixth ribs, is caused mainly by the apex of the heart striking against the chest walls, assisted by the distention of the great vessels about the base of the heart.

Sounds of the Heart.—If the ear be placed over the cardiac region,

two distinct sounds are heard during each revolution of the heart, closely following each other and which differ in character.

The sound coinciding with the systole in point of time, the *first sound*, is long and dull, and caused by the closure and vibration of the auriculo-ventricular valves, the contraction of the walls of the ventricles, and the apex beat; the *second sound*, occurring during the *diastole*, is short and sharp, and caused by the closure of the semilunar valves.

The *capacity* of the left ventricle when fully distended is estimated at from four to seven ounces.

The Frequency of the Heart's Action varies at different periods of life, but in the adult male it beats about 72 times per minute. It is influenced by age, exercise, posture, digestion, etc.

Age.—Before birth, the *number of pulsations* per minute averages	140
During the first year it diminishes to	128
During the third year diminishes to	95
From the eighth to the fourteenth year averages	84
In adult life the average is	72

Exercise and *digestion* increase the frequency of the heart's action.

Posture influences the number of pulsations per minutė; in the male, standing, the average is 81; sitting, 71; lying, 66;—independent, for the most part, of muscular effort.

The Rhythmic Movements of the heart are dependent upon—

1. An inherent irritability of the muscular fiber, which manifests itself as long as the nutrition is maintained.
2. The continuous flow of blood through its cavities, distending them and stimulating the endocardium.

The Force Exerted by the Left Ventricle at each contraction has been estimated at 52 pounds. If a tube be inserted into the aorta the pressure there will be sufficient to support a column of blood nine feet, or a column of mercury six inches, in height, the weight in either case being about four pounds. The estimation of the force which the heart is required to exert to support this column of blood is arrived at by multiplying the pressure in the aorta (four pounds) by the area of the internal surface of the left ventricle (about 13 inches), each inch of the ventricle being capable of supporting a downward pressure of four pounds.

Work Done by the Heart.—The work done by the heart is estimated by multiplying the amount of blood sent out from the right and left ventricles at each contraction by the pressure in the pulmonary artery and

aorta respectively; *e.g.*, when the right ventricle contracts it forces out one-quarter pound of blood, and in so doing must overcome a pressure in the pulmonary artery sufficient to support a column of blood three feet in height; that is, must exert energy sufficient to raise $\frac{1}{4}$ pound 3 feet, or $\frac{1}{4} \times 3$ or $\frac{3}{4}$ pound 1 foot. When the left ventricle contracts it sends out $\frac{1}{4}$ pound of blood, and in so doing the left ventricle must overcome a pressure in the aorta sufficient to support a column of blood 9 feet in height; that is, must exert energy sufficient to raise $\frac{1}{4}$ pound 9 feet, or $\frac{1}{4} \times 9$ or $2\frac{1}{4}$ pounds 1 foot. Work done is estimated by the amount of energy required to raise a definite weight a definite height; the unit, the foot-pound, being that required to raise one pound one foot.

The heart, therefore, at each systole exerts energy sufficient to raise 3 foot-pounds, and as it contracts 72 times per minute, it would raise in that time 3×72 or 216 foot-pounds; and in one hour 216×60 or 12,960 foot-pounds; and in twenty-four hours $12{,}960 \times 24$ or 311,040 foot-pounds, or 138.5 foot-tons.

Influence of the Nervous System upon the Heart.—When the heart of a frog is removed from the body it continues to beat for a variable length of time, depending upon the nature of the conditions surrounding it. The heart of warm-blooded animals continues to beat but for a very short time. The cause of the continued pulsations of the frog heart is the presence of nervous ganglia in its substance. These ganglia have not been shown to exist in the mammalian heart, but there is reason to believe that the nervous mechanism is fundamentally the same.

The ganglia of the heart are three in number, one situated at the opening of the inferior vena cava (the ganglion of Remak), a second situated in the auriculoventricular septum (the ganglion of Biddle), and a third situated in the interauricular septum (the ganglion of Ludwig). The first two are motor in function and excite the pulsations of the heart; the third is inhibitory in function and retards the action of the heart. The actions of these ganglia, though for the most part automatic, are modified by impressions coming through nerves from the medulla oblongata. When the inhibitory center is stimulated by muscarin the heart is arrested in diastole; when atropia is applied the heart recommences to beat, because atropia paralyzes the inhibitory center.

The nerves modifying the action of the heart are the pneumogastric (vagus) and the accelerator nerves.

The *pneumogastric nerve*, after emerging from the medulla, receives motor fibers from the spinal accessory nerve. It then passes downward, giving off branches, some of which terminate in the inhibitory ganglion.

Stimulation of the vagus, by increasing the activity of the inhibitory center, arrests the heart in diastole with its cavities full of blood; but as the stimulation is only temporary, after a few seconds the heart recommences to beat; at first the pulsations are weak and feeble, but soon regain their original vigor. After the administration of atropia in sufficient doses to destroy the termination of the pneumogastric, stimulation of its trunk has no effect upon the heart. The inhibitory fibers in the vagus are constantly in action, for *division* of the nerve on both sides is always followed by an increase in the frequency of the heart's pulsations.

The *accelerator fibers* arise in the medulla, pass down the cord, emerge in the cervical region, pass to the last cervical and first dorsal ganglia of the sympathetic, and thence to the heart. *Stimulation* of these fibers causes an increased frequency of the heart's pulsations, but they are diminished in force.

ARTERIES.

The Arteries are a series of branching tubes conveying blood to all portions of the body. They are composed of three coats:—

1. *External*, formed of areolar and elastic tissue.
2. *Middle*, contains both elastic and muscular fibers, arranged transversely to the long axis of the artery. The elastic tissue is more abundant in the larger vessels, the muscular in the smaller.
3. *Internal*, composed of a thin homogeneous membrane, covered with a layer of elongated endothelial cells.

The arteries possess both *elasticity* and *contractility*.

The property of elasticity allows the arteries already full to accommodate themselves to the incoming amount of blood, and to convert the intermittent acceleration of blood in the large vessels into a steady and continuous stream in the capillaries.

The *contractility* of the smaller vessels equalizes the current of blood, regulates the amount going to each part, and promotes the onward flow of blood.

Blood Pressure.—Under the influence of the ventricular systole, the recoil of the elastic walls of the arteries, and the resistance offered by the capillaries, the blood is constantly being subjected to a certain amount of pressure. If a large artery of an animal be divided, and a glass tube of the same caliber be inserted into its orifice, the blood will rise to a height of about nine feet; or if it be connected with a mercurial manometer, the mercury will rise to a height of six inches. This height will be a measure of the pressure in the vessel. The absolute quantity of mercury sustained

by an artery can be arrived at by multiplying the height of the column by the area of a transverse section of that artery.

The pressure of the blood is greatest in the large arteries, but gradually decreases toward the capillaries.

The blood pressure is increased or diminished by influences acting upon the heart or upon the peripheral resistance of the capillaries, viz.:—

If, while the force of the heart remains the same, the number of pulsations per minute increases, thus increasing the volume of blood in the arteries, the pressure rises. If the rate remains the same, but the force increases, the pressure again rises. Causes that increase the peripheral resistance by contracting the arterioles, *e.g.*, vasomotor nerves, cold, etc., produce an increase of the pressure.

On the other hand, influences which *diminish* either the volume of the blood, or the number of pulsations, or the force of the heart, or the peripheral resistance, *lower* the pressure.

The Pulse is the sudden distention of the artery in a transverse and longitudinal direction, due to the injection of a volume of blood into the arteries at the time of the ventricular systole. As the vessels are already full of blood, they must expand in order to accommodate themselves to the incoming volume of blood. The blood pressure is thus increased, and the pressure originating at the ventricle excites a *pulse wave*, which passes from the heart toward the capillaries at the rate of about twenty-nine feet per second. It is this wave that is appreciated by the finger.

The Velocity with which the blood flows in the arteries diminishes from the heart to the capillaries, owing to an increase in the united sectional area of the vessels, and increases in rapidity from the capillaries toward the heart. It moves most rapidly in the large vessels, and especially under the influence of the ventricular systole. From experiments on animals, it has been estimated to move in the carotid of man at the rate of sixteen inches per second, and in the large veins at the rate of four inches per second.

The Caliber of the Blood-vessels is regulated by the *vasomotor* nerves, which have their origin in the gray matter of the medulla oblongata. They issue from the spinal cord through the anterior roots of spinal nerves, pass through the sympathetic ganglia, and ultimately are distributed to the coats of the blood-vessels. They exert at different times a constricting and dilating action upon the vessels, thus keeping up the arterial tonus.

Capillaries.—The capillaries constitute a network of vessels of microscopic size, which distribute the blood to the inmost recesses of the tissues,

inosculating with the arteries on the one hand and the veins on the other; they branch and communicate in every possible direction.

The diameter of a capillary vessel varies from the $\frac{1}{6000}$ths to the $\frac{1}{3000}$ths of an inch; their walls consist of a delicate homogeneous membrane, the $\frac{1}{20000}$ths of an inch in thickness, lined by flattened, elongated, endothelial cells, between which, here and there, are observed *stomata*.

It is through the agency of the capillary vessels that the phenomena of nutrition and secretion take place, for here the blood flows in an equable and continuous current, and is brought into intimate relationship with the tissues—two of the essential conditions for proper nutrition.

The *rate* of *movement* in the capillary vessels is estimated at one inch in thirty seconds.

In the capillary current the red corpuscles may be seen hurrying down the center of the stream, while the white corpuscles in the still layer adhere to the walls of the vessel, and at times can be seen to pass through the walls of the vessel by ameboid movements.

The Passage of the Blood through the capillaries is mainly due to the force of the ventricular systole and the elasticity of the arteries; but it is probably also aided by a power resident in the capillaries themselves, the result of a vital relation between the blood and the tissues.

The Veins are the vessels which return the blood to the heart; they have their origin in the venous radicles, and as they approach the heart converge to form larger trunks, and terminate finally in the venæ cavæ.

They possess three coats—

1. *External*, made up of areolar tissue.
2. *Middle*, composed of nonstriated muscular fibers, yellow, elastic, and fibrous tissue.
3. *Internal*, an endothelial membrane, similar to that of the arteries.

Veins are distinguished by the possession of valves throughout their course, which are arranged in pairs, and formed by a reflection of the internal coat, strengthened by fibrous tissues; they always look toward the heart, and when closed prevent a return of blood in the veins. Valves are most numerous in the veins of the extremities, but are entirely absent in many others.

The Onward Flow of Blood in the veins is mainly due to the action of the heart, but is assisted by the contraction of the voluntary muscles and the force of respiration.

Muscular contraction, which is intermittent, aids the flow of blood in the

veins by compressing them. As regurgitation is prevented by the closure of the valves, the blood is forced onward toward the heart.

Rhythmic movements of veins have been observed in some of the lower animals, aiding the onward current of blood.

During the movement of *inspiration* the thorax is enlarged in all its diameters, and the pressure on its contents at once diminishes. Under these circumstances a suction force is exerted upon the great venous trunks, which causes the blood to flow with increased rapidity and volume toward the heart.

Venous Pressure.—As the force of the heart is nearly expended in driving the blood through the capillaries, the pressure in the venous system is not very marked, not amounting in the jugular vein of a dog to more than $\frac{1}{12}$th that of the carotid artery.

The time required for a complete circulation of the blood throughout the vascular system has been estimated to be from twenty to thirty seconds, while for the *entire mass* of blood to pass through the heart 58 pulsations would be required, occupying forty-eight seconds.

The Forces keeping the blood in circulation are—

1. Action of the heart.
2. Elasticity of the arteries.
3. Capillary force.
4. Contraction of the voluntary muscles upon the veins.
5. Respiratory movements.

RESPIRATION.

Respiration is the function by which oxygen is absorbed into the blood and carbonic acid exhaled. The appropriation of the oxygen and the evolution of carbonic acid takes place in the tissues as a part of the general nutritive process, the blood and respiratory apparatus constituting the media by means of which the interchange of gases is accomplished.

The Respiratory Apparatus consists of the larynx, trachea, and lungs.

The Larynx is composed of firm cartilages, united together by ligaments and muscles; running anteroposteriorly across the upper opening are four ligamentous bands, the two superior, or *false* vocal cords, and the two inferior, or *true* vocal cords, formed by folds of the mucous membrane. They are attached anteriorly to the thyroid cartilages and posteriorly to the

arytenoid cartilages, and are capable of being separated by the contraction of the posterior crico-arytenoid muscles, so as to admit the passage of air into and from the lungs.

The Trachea is a tube from four to five inches in length, three-quarters of an inch in diameter, extending from the cricoid cartilage of the larynx to the third dorsal vertebra, where it divides into the right and left bronchi. It is composed of a series of cartilaginous rings, which extend about two-thirds around its circumference, the posterior third being occupied by fibrous tissue and nonstriated muscular fibers, which are capable of diminishing its caliber.

The trachea is covered externally by a tough, fibro-elastic membrane, and internally by mucous membrane, lined by columnar ciliated epithelial cells. The cilia are always waving from within outward. When the two bronchi enter the lungs they divide and subdivide into numerous and smaller branches, which penetrate the lung in every direction until they finally terminate in the *pulmonary lobules.*

As the bronchial tubes become smaller their walls become thinner; the cartilaginous rings disappear, but are replaced by irregular angular plates of cartilage; when the tube becomes less than the $\frac{1}{50}$th of an inch in diameter they wholly disappear, and the fibrous and mucous coats blend together, forming a delicate elastic membrane, with circular muscular fibers.

The Lungs occupy the cavity of the thorax, are conical in shape, of a pink color and a spongy texture. They are composed of a great number of distinct lobules, the *pulmonary lobules,* connected together by interlobular connective tissue. These lobules vary in size, are of an oblong shape, and are composed of the ultimate ramifications of the bronchial tubes, within which are contained the *air vesicles* or *cells.* The walls of the air vesicles, exceedingly thin and delicate, are lined internally by a layer of tessellated epithelium, externally covered by elastic fibers, which give the lungs their elasticity and distensibility.

The Venous Blood is distributed to the lungs for aëration by the pulmonary artery, the terminal branches of which form a rich plexus of capillary vessels surrounding the air cells; the air and blood are thus brought into intimate relationship, being separated only by the delicate walls of the air cells and capillaries.

The thoracic cavity in which the respiratory organs are lodged is of a conical shape, having its apex directed upward, its base downward. Its frame-work is formed posteriorly by the spinal column, anteriorly by the sternum, and laterally by the ribs and costal cartilages. Between and over

the ribs lie muscles, fascia, and skin; above, the thorax is completely closed by the structures passing into it and by the cervical fascia and skin; below, it is closed by the diaphragm. It is therefore an air-tight cavity.

The Pleura.—Each lung is surrounded by a closed serous membrane, the pleura, one layer of which, the *visceral*, is reflected over the lung, the other, the *parietal*, reflected over the wall of the thorax; between the two layers is a small amount of fluid which prevents friction during the play of the lungs in respiration.

Owing to the elastic tissue which is present in the lungs, they are very readily distensible, so much so, indeed, that the pressure of the air inside the trachea and lungs is sufficient to distend them until they completely fill all parts of the thoracic cavity not occupied by the heart and great vessels. The elastic tissue endows them not only with distensibility, but also with the power of elastic recoil, by which they are enabled to accommodate themselves to all variations in the size of the thoracic cavity.

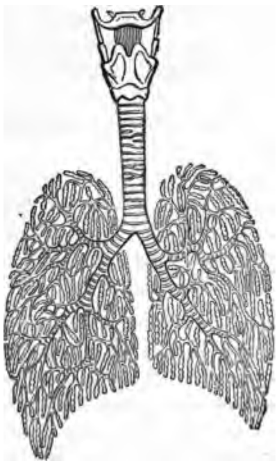

FIG. 13.—DIAGRAM OF THE RESPIRATORY ORGANS.
The windpipe leading down from the larynx is seen to branch into two large bronchi, which subdivide after they enter their respective lungs.

When the chest walls recede the air within the lungs expands and presses them against the ribs; when the chest walls contract, the air being driven out, the elastic tissue recoils and the lungs return to their original condition. The movements of the lungs are therefore entirely passive.

As the capacity of the chest in a state of rest is greater than the volume of the lungs after they are collapsed, it is quite evident that in the living condition the lungs are distended and in a state of elastic tension, which is greater or less in proportion as the thoracic cavity is increased or diminished in size. The elastic tissue, always on the stretch, is endeavoring to pull the visceral layer of the pleura away from the parietal layer, but is antagonized by the pressure of the air within the air passages. This condition of things persists as long as the thoracic cavity remains air tight; but if an opening be made in the thoracic wall, the pressure of the external air which was previously supported by the practically rigid walls of the thorax

now presses upon the lung with as much force as the air within the lung. The two pressures being neutralized, there is nothing to prevent the elastic tissue from recoiling, driving the air out, and collapsing. The elastic tension of the lungs can be readily measured in man after death by inserting a manometer into the trachea. Upon opening the thorax and allowing the tissue to recoil, the air presses upon the mercury and elevates it, the extent to which it is raised being the index of the pressure. Hutchinson calculated the pressure to be one-half pound to the square inch of the lung surface.

Respiratory Movements.—The movements of respiration are two, and consist of an alternate dilatation and contraction of the chest, known as inspiration and expiration.

1. *Inspiration* is an active process, the result of the expansion of the thorax, whereby air is introduced into the lungs.
2. *Expiration* is a partially passive process, the result of the recoil of the elastic walls of the thorax, and the recoil of the elastic tissue of the lungs, whereby the carbonic acid is expelled.

In Inspiration the chest is enlarged by an increase in all its diameters, viz.:—

1. The *vertical* is increased by the contraction and descent of the diaphragm when it approximates a straight line.
2. The *anteroposterior* and *transverse* diameters are increased by the elevation and rotation of the ribs upon their axes.

In *ordinary tranquil inspiration* the muscles which elevate the ribs and thrust the sternum forward, and so increase the diameters of the chest, are the *external intercostals*, running from above downward and forward, the *sternal portion* of the *internal intercostals*, and the *levatores costarum.*

In the *extraordinary efforts of inspiration* certain auxiliary muscles are brought into play, viz.: the *sternomastoid*, *pectorales*, *serratus magnus*, which increase the capacity of the thorax to its utmost limit.

In Expiration the diameters of the chest are all diminished, viz.:—

1. The *vertical*, by the ascent of the diaphragm.
2. The *anteroposterior*, by a depression of the ribs and sternum.

In *ordinary tranquil expiration* the diameters of the thorax are diminished by the recoil of the elastic tissue of the lungs and the ribs; but in forcible expiration the muscles which depress the ribs and sternum, and thus further diminish the diameter of the chest, are the *internal intercostals*, the *infracostals*, and the *triangularis sterni.*

In the *extraordinary efforts of expiration* certain auxiliary muscles are

brought into play, viz.: the *abdominal* and *sacrolumbalis muscles*, which diminish the capacity of the thorax to its utmost limit.

Expiration is aided by the recoil of the elastic tissue of the lungs and ribs and the pressure of the air.

Movements of the Glottis.—At each inspiration the *rimaglottidis* is dilated by a separation of the vocal cords, produced by the contraction of the *crico-arytenoid* muscles, so as to freely admit the passage of air into the lungs: in expiration they fall passively together, but do not interfere with the exit of air from the chest.

Nervous Mechanism of Respiration.—The movements of respiratory muscles, though capable of being modified to a certain extent by efforts of the will, are of an automatic character, and called forth by nervous impulses emanating from the medulla oblongata. The respiratory center, the so called vital point, generates the nerve impulses, which, traveling outward through the phrenic and intercostal nerves, excite contractions of the diaphragm and intercostal muscles respectively. This center is for the most part automatic in its action, though it is capable of being modified by impulses reflected to it through various sensory nerves.

This center may be stimulated:—

1. *Directly*, by the condition of the blood. An increase of carbonic acid or a diminution of oxygen in the blood causes an acceleration of the respiratory movements; the reverse of these conditions causes a diminution of the respiratory movements.
2. *Indirectly*, by reflex action. The medulla may be excited to action through the pneumogastric nerve, by the presence of carbonic acid in the lungs irritating its terminal filaments; through the fifth nerve, by irritation of the terminal branches; and through the nerves of general sensibility. In either case this center reflects *motor* impulses to the respiratory muscles through the *phrenic, intercostals, inferior laryngeal*, and other nerves.

Types of Respiration.—The *abdominal type* is most marked in young children, irrespective of sex, the respiratory movements being effected by the diaphragm and abdominal muscles.

In the *superior costal type*, exhibited by the adult female, the respiratory movements are more marked in the upper part of the chest, from the 1st to the 7th ribs, permitting the uterus to ascend in the abdomen during pregnancy without interfering with respiration.

In the *inferior costal type*, manifested by the male, the movements are

largely produced by the muscles of the lower portions of the chest, from the 7th rib downward, assisted by the diaphragm.

The respiratory movements vary according to age, sleep, and exercise, being most frequent in early life, but averaging 20 per minute in adult life. They are diminished by sleep and increased by exercise. There are about four pulsations of the heart to each respiratory act.

During inspiration *two sounds* are produced; the one, heard in the thorax, in the trachea and larger bronchial tubes, is *tubular* in character; the other, heard in the substance of the lungs, is *vesicular* in character.

AMOUNT OF AIR EXCHANGED IN RESPIRATION, AND CAPACITY OF LUNGS.

The *tidal* or *breathing volume* of air, that which passes in and out of the lungs at each inspiration and expiration, is estimated at from 20 to 30 cubic inches.

The *complemental air* is that amount which can be taken into the lungs by a forced inspiration, in addition to the ordinary tidal volume, and amounts to about 110 cubic inches.

The *reserve air* is that which usually remains in the chest after the ordinary efforts of expiration, but which can be expelled by forcible expiration. The volume of reserve air is about 100 cubic inches.

The *residual air* is that portion which remains in the chest and cannot be expelled after the most forcible expiratory efforts, and which amounts, according to Dr. Hutchinson, to about 100 cubic inches.

The Vital Capacity of the chest indicates the amount of air that can be forcibly expelled from the lungs after the deepest possible inspiration, and is an index of an individual's power of breathing in disease and prolonged severe exercise. The combined amounts of the tidal, the complemental, and reserve air, 230 cubic inches, represents the vital capacity of an individual five feet seven inches in height. The vital capacity varies chiefly with stature. It is increased eight cubic inches for every inch in height above this standard, and diminishes eight cubic inches for each inch below it.

The Tidal Volume of air is carried only into the trachea and large bronchial tubes by the inspiratory movements. It reaches the deeper portions of the lungs in obedience to the law of diffusion of gases, which is inversely proportionate to the square root of their densities.

The *ciliary action* of the columnar cells lining the bronchial tubes also assists in the interchange of air and carbonic acid.

The *entire volume of air* passing in and out of the thorax in twenty-four hours is subject to great variation, but can be readily estimated from the tidal volume and the number of respirations per minute. Assuming that an individual takes into the chest 20 cubic inches at each inspiration, and breathes 18 times per minute, in twenty-four hours there would pass in and out of the lungs 518,400 cubic inches, or 300 cubic feet.

Chemistry of Respiration.—As the inspired air undergoes a change in composition during its stay in the lungs which renders it unfit for further respiration, it becomes requisite, for the correct understanding of respiration, to ascertain the composition of both inspired and expired air.

Composition of Air. — Chemic analysis has shown that every 100 volumes of air contains 20.81 volumes of oxygen, and 70.19 volumes of nitrogen, and 0.03 volume of carbonic acid. Aqueous vapor is also present, though the quantity is variable. The higher the temperature the greater the amount.

The Changes in the Air effected by respiration are—

Loss of oxygen, to the extent of five cubic inches per 100 of air, or one in 20.

Gain of carbonic acid, to the extent of 4.66 cubic inches per 100 of air, or .93 inch in 20.

Increase of water vapor and organic matter.

Elevation of temperature.

Increase, and at times decrease, of nitrogen.

Gain of ammonia.

The *total quantity* of *oxygen* withdrawn from the air and consumed by the body in twenty-four hours amounts to 15 cubic feet, and can be readily estimated from the amount consumed at each respiration. Assuming that one cubic inch of oxygen remains in the lungs at each respiration, in one hour there are consumed 1080 cubic inches, and in twenty-four hours 25,920 cubic inches, or 15 cubic feet, weighing 18 ounces. To obtain this quantity, 300 cubic feet of air are necessary.

The quantity of oxygen consumed daily is subject to considerable variations. It is *increased* by exercise, digestion, and lowered temperature, and decreased by the opposite conditions.

The *quantity* of *carbonic acid* exhaled in twenty-four hours varies greatly. It can be estimated in the same way. Assuming that an individual exhales .93+ cubic inch at each respiration, in one hour there are eliminated 1008 cubic inches, and in twenty-four hours 24,192 cubic inches, or 14 cubic feet, containing seven ounces of pure carbon.

The exhalation of carbonic acid is *increased* by muscular exercise, nitrogenous food, tea, coffee, and rice, age, and by muscular development; *decreased* by a lowering of temperature, repose, gin and brandy, and a dry condition of the air.

As there is always more oxygen consumed than carbonic acid exhaled, and as oxygen unites with carbon to form an equal volume of carbonic acid, it is evident that a certain quantity of oxygen disappears within the body. In all probability it unites with the sulphur hydrogen of the food to form water.

The *amount* of *watery vapor* which passes out of the body with the expired air is estimated at from one to two pounds.

The *organic matter*, though slight in amount, gives the odor to the breath. In a room with defective ventilation the organic matter accumulates and gives rise to headache, nausea, drowsiness, etc. Long-continued breathing of such air produces general ill health. It is not so much the presence of CO_2 in increased amount as the presence of organic matter which necessitates thorough ventilation.

Condition of the Gases in the Blood.

Oxygen is absorbed from the lungs into the arterial blood by the coloring matter, *hemoglobin*, with which it exists in a state of loose combination, and is disengaged during the process of nutrition.

Carbonic acid, arising in the tissues, is absorbed into the blood in consequence of its alkalinity, where it exists in a state of simple solution and also in a state of feeble combination with the carbonates, soda and potassa, forming the bicarbonates.

Nitrogen is simply held in solution in the plasma.

Exchange of Gases in the Air Cells.—From the difference in tension of the oxygen in the air cells (27.44 mm. of Hg) and of the oxygen in the venous blood (22 mm. Hg), and from the difference of the carbonic acid tension in the venous blood (41 mm. Hg) and in the air cells (27 mm. Hg), it might be concluded that the passage of the gases may be due solely to pressure. The absorption of oxygen, however, does not follow absolutely the law of pressure; that chemic processes are involved is shown by the union of oxygen with the hemoglobin of the blood corpuscles. The exhalation of CO_2 is also partly a chemic process, as it has been shown that the quantity excreted is greatly increased when oxygen is simultaneously absorbed. Oxygen not only favors the exhalation of loosely combined CO_2, but favors the expulsion of that which can only be excreted by the addition of acids to the blood.

Changes in the Blood during Respiration.

As the blood passes through the lungs it is changed in *color*, from the dark purple hue of venous blood to the bright red scarlet of arterial blood.

The heterogeneous composition of venous blood is exchanged for the uniform composition of the arterial.

It gains oxygen and loses carbonic acid.

Its coagulability is increased. Temperature is diminished.

Asphyxia.—If the supply of oxygen to the lungs be diminished and the carbonic acid retained in the blood, the normal respiratory movements cease, the condition of asphyxia ensues, which soon terminates in death.

The *phenomena* of asphyxia are violent spasmodic action of the respiratory muscles attended by convulsions of the muscles of the extremities, engorgement of the venous system, lividity of the skin, abolition of sensibility and reflex action, and death.

The *cause* of *death* is a paralysis of the heart from over distention by blood. The passage of the blood through the capillaries is prevented by contraction of the smaller arteries, from irritation of the vasomotor center. The heart is enfeebled by a want of oxygen and inhibited in its action by the inhibitory centers.

ANIMAL HEAT.

The Functional Activity of all the organs and tissues of the body is attended by the evolution of heat, which is independent, for the most part, of external conditions. Heat is a *necessary condition* for the due performance of all vital actions; although the body constantly loses heat by *radiation* and *evaporation*, it possesses the capability of renewing it and maintaining it at a fixed standard. The *normal temperature* of the body in the adult, as shown by means of a delicate thermometer placed in the axilla, ranges from 97.25° F. to 99.5° F., though the *mean normal* temperature is estimated by Wunderlich at 98.6° F.

The temperature varies in different portions of the body according to the degree in which oxidation takes place, being the highest in the muscles during exercise, in the brain, blood, liver, etc.

The Conditions which Produce Variations in the normal temperature of the body are age, period of the day, exercise, food and drink, climate, season, and disease.

Age.—At birth the temperature of the infant is about 1° F. above that of the adult, but in a few hours falls to 95.5° F., to be followed in the course

of twenty-four hours by a rise to the normal or a degree beyond. During childhood the temperature approaches that of the adult; in aged persons the temperature remains about the same, though they are not as capable of resisting the depressing effects of external cold as adults. A *diurnal variation* of the temperature occurs from 1.8° F. to 3.7° F. (Jürgensen); the *maximum* occurring late in the afternoon, from 4 to 9 P.M., the *minimum*, early in the morning, from 1 to 7 A. M.

Exercise.—The temperature is raised from 1° to 2° F. during active contractions of the muscular masses, and is probably due to the increased activity of chemic changes; a rise beyond this point being prevented by its diffusion to the surface, consequent on a more rapid circulation, radiation, more rapid breathing, etc.

Food and Drink.—The ingestion of a hearty meal increases the temperature but slightly; an absence of food, as in starvation, produces a marked decrease. Alcoholic drinks, in large amounts, in persons unaccustomed to their use, cause a depression of the temperature amounting to from 1° to 2° F. Tea causes a slight elevation.

External Temperature.—Long-continued exposure to cold, especially if the body is at rest, diminishes the temperature from 1° to 2° F., while exposure to a great heat slightly increases it.

Disease frequently causes a marked variation in the normal temperature of the body, rising as high as 107° F. in typhoid fever, and 105° F. in pneumonia; in cholera it falls as low as 80° F. Death usually occurs when the heat remains high and persistent, from 106° to 110° F.; the increase of heat in disease is due to excessive production rather than to diminished elimination.

The Source of Heat is to be sought for in the chemic decompositions and hydrations taking place during the general process of nutrition, and the combustion of the carbonaceous compounds by the oxygen of the inspired air; the amount of its production is in proportion to the activity of the internal changes.

Every contraction of a muscle, every act of secretion, each exhibition of nerve force, is accompanied by a change in the chemic composition of the tissues and an evolution of heat. The reduction of the disintegrated tissues to their simplest form by oxidation, the combination of the oxygen of the inspired air with the carbon and hydrogen of the blood and tissues, results in the formation of carbonic acid and water and the generation of a large amount of heat.

Certain elements of the food, particularly the *nonnitrogenized* substances, undergo oxidation without taking part in the formation of the tis-

sues, being transformed into carbonic acid and water, and thus increase the sum of heat in the body.

Heat-producing Tissues.—All the tissues of the body add to the general amount of heat, according to the degree of their activity. But special structures, on account of their mass and the large amount of blood they receive, are particularly to be regarded as *heat producers; e.g.* :—

1. During mental activity the *brain* receives nearly one-fifth of the entire volume of blood, and the venous blood returning from it is charged with waste matters, and its temperature is increased.
2. The *muscular tissue*, on account of the many chemic changes occurring during active contractions, must be regarded as the chief heat-producing tissue.
3. The *secreting glands*, during their functional activity, add largely to the amount of heat.

The entire quantity of heat generated within the body has been demonstrated experimentally to be about 2300 calories, a calory or heat unit being that amount of heat required to raise the temperature of one kilo. of water (2.2 pounds) 1° C. This quantity of heat, if not utilized and retained within the body, would elevate its temperature in twenty-four hours about 60° F. That this volume of heat depends very largely upon the oxidation of the food stuffs can be shown experimentally.

The normal temperature of the body is maintained by a constant expenditure of the heat in several directions :—

1. In warming the food, drink, and air that are consumed in twenty-four hours. For this purpose about 157 heat units are required.
2. In evaporating water from the skin and lungs; 619 heat units being utilized for this purpose.
3. In radiation and conduction. By these processes the body loses at least 50 per cent. of its heat, or 1156 heat units.
4. In the production of work; the work of the circulatory, respiratory, muscular, and nervous apparatus being performed by the transformation of 369 heat units into units of work.

The *nervous system* influences the production of heat in a part by increasing the amount of blood going through it by its action upon the vasomotor nerves. Whether there exists a special heat center has not been satisfactorily determined, though this is probable.

SECRETION.

The Process of Secretion consists in the separation of materials from the blood which are either to be again utilized to fulfil some special purpose in the economy, or are to be removed from the body as excrementitious matter; in the former case they constitute the *secretions*, in the latter, the *excretions*.

The *materials* which enter into the composition of the *secretions* are derived from the nutritive principles of the blood, and require special organs, *e. g.*, gastric glands, mammary glands, etc., for their proper elaboration.

The *materials* which compose the *excretions* preexist in the blood, and are the results of the activities of the nutritive process; if retained within the body they exert a deleterious influence upon the composition of the blood.

Destruction of a secreting gland abolishes the secretion peculiar to it, and it cannot be formed by any other gland; but among the excreting organs there exists a complementary relation, so that if the function of one organ be interfered with, another performs it to a certain extent.

CLASSIFICATION OF THE SECRETIONS.

PERMANENT FLUIDS.

Serous fluids.
Synovial fluid.
Aqueous humor of the eye.
Vitreous humor of the eye.
Fluid of the labyrinth of the internal ear.
Cerebrospinal fluid.

TRANSITORY FLUIDS.

Mucus.
Sebaceous matter.
Cerumen (external meatus).
Meibomian fluid
Milk and colostrum.
Tears.
Saliva.
Gastric juice.
Pancreatic juice.
Secretion from Brunner's glands.
Secretion from Lieberkühn's glands.
Secretions from follicles of the large intestine.
Bile (also an excretion).

EXCRETIONS.

Perspiration and the secretion of the axillary glands.
Urine.
Bile (also a secretion).

FLUIDS CONTAINING FORMED ANATOMIC ELEMENTS.

Seminal fluid, containing spermatozoids.
Fluid of the Graafian follicles.

The Essential Apparatus for secretion is a delicate, homogeneous, structureless *membrane*, on one side of which, in close contact, is a capillary plexus of *blood-vessels*, and on the other side a layer of *cells* whose physiologic function varies in different situations.

Secreting organs may be divided into *membranes* and *glands*.

Serous membranes usually exist as closed sacs, the inner surface of which is covered by pale, nucleated epithelium, containing a small amount of secretion.

The serous membranes are the *pleura*, *peritoneum*, *pericardium*, *synovial sacs*, etc.

The *serous fluids* are of a pale amber color, somewhat viscid, alkaline, coagulable by heat, and resemble the serum of the blood; their *amount* is but small; the pleural varies from four to seven drams; the peritoneal from one to four ounces; the pericardial from one to three drams.

The *synovial fluid* is colorless, alkaline, and extremely viscid, from the presence of *synovin*.

The *function* of serous fluids is to moisten the opposing surfaces, so as to prevent friction during the play of the viscera.

The *mucous membranes* are soft and velvety in character, and line the cavities and passages leading to the exterior of the body; *e.g.*, the *gastro-intestinal*, *pulmonary*, and *genito-urinary*. They consist of a primary basement membrane covered with epithelial cells, which in some situations are tessellated, in others, columnar.

Mucus is a pale, semitransparent, alkaline fluid, containing epithelial cells and leukocytes. It is composed, chemically, of water, an albuminous principle, *mucosin*, and mineral salts; the principal varieties are nasal, bronchial, vaginal, and urinary.

Secreting Glands are formed of the same elements as the secreting membranes, but instead of presenting flat surfaces, are involuted, forming tubules, which may be *simple follicles*, *e. g.*, mucous, uterine, or intestinal; or *compound follicles*, *e. g.*, gastric glands, mammary glands; or *racemose glands*, *e. g.*, salivary glands and pancreas. They are composed of a basement membrane, enveloped by a plexus of blood-vessels, and are lined by epithelial and *true secreting cells*, which in different glands possess the capability of elaborating elements characteristic of their secretions.

In the Production of the Secretion two essentially different processes are concerned :—

1. *Chemic.*—The formation and elaboration of the characteristic organic ingredients of the secreted fluids, *e. g.*, pepsin, pancreatin, takes place

during the intervals of glandular activity, as a part of the general function of nutrition. They are formed by the cells lining the glands, and can often be seen in their interior with the aid of the microscope; *e. g.*, bile in the liver cells, fat in the cells of the mammary gland.

2. *Physical.*—Consisting of a transudation of water and mineral salts from the blood into the interior of the gland.

During the intervals of glandular activity only that amount of blood passes through the gland sufficient for proper nutrition; when the gland begins to secrete, under the influence of an appropriate stimulus, the blood-vessels dilate and the quantity of blood becomes greatly increased beyond that flowing through the gland during its repose.

Under these Conditions a transudation of water and salt takes place, washing out the characteristic ingredients, which are discharged by the gland ducts. The *discharge* of the secretions is intermittent; they are retained in the glands until they receive the appropriate stimulus, when they pass into the larger ducts by the vis a tergo, and are then discharged by the contraction of the muscular walls of the ducts.

The *activity* of glandular secretion is hastened by an increase in the blood pressure and retarded by a diminution.

The *nervous centers* in the medulla oblongata influence secretion—

1. By increasing or diminishing the amount of blood entering a gland.
2. By exerting a direct influence upon the secreting cells themselves, the centers being excited by reflex irritation, mental emotion, etc.

MAMMARY GLANDS.

The Mammary Glands, which secrete the milk, are two more or less hemispherical organs, situated in the human female on the anterior surface of the chest. Though rudimentary in childhood, they gradually increase in size as the young female approaches puberty.

The gland presents at its convexity a small prominence of skin, the nipple, which is surrounded by a circular area of pigmented skin, the areola. The gland proper is covered by a layer of adipose tissue anteriorly and attached posteriorly to the pectoral muscles by a meshwork of fibrous tissue.

During uterogestation the mammary glands become larger, firmer, and more lobulated; the areola darkens and the veins become more prominent. At the period of lactation the gland is the seat of active histologic and physiologic changes, correlated with the production of milk. At the close of lactation the glands diminish in size, undergo involution, and gradually return to their original nonsecreting condition.

Structure of the Mammary Glands.—Each mammary gland consists of an aggregation of some 15 or 20 lobes, each one of which is surrounded by a framework of fibrous tissue. The lobe is provided with an excretory duct, which, as it approaches the base of the nipple, expands to form a sinus or reservoir, beyond which it opens by a narrowed orifice on the surface of the nipple. On tracing the duct into a lobe it is found to divide and subdivide, and finally terminate in lobules or acini. Each acinus consists of a basement membrane, lined by low polyhedral cells. Externally it is surrounded by connective tissue, supporting blood-vessels, lymphatics, and nerves.

MILK.

Milk is an opaque, bluish-white fluid, almost inodorous, of a sweet taste, an alkaline reaction, and a specific gravity of 1.025 to 1.040. When examined microscopically it is seen to consist of a clear fluid, the *milk plasma*, holding in suspension an enormous number of small, highly refractive oil globules, which measure, on the average, the $\frac{1}{10000}$th of an inch in diameter. Each globule is supposed by some observers to be surrounded by a thin, albuminous envelope, which enables it to maintain the discrete form. *The quantity* of milk secreted daily by the human female averages about two and a half pints. The milk of all the mammalia consists of all the different classes of nutritive principles, though in varying proportions. The relative proportions in which these constituents exist are shown in the following table of analyses :—

COMPOSITION OF MILK.

In 100 Parts.	Human.	Cow.	Goat.	Ass.	Sheep.	Mare.
Water, ...	88.00	86.87	87.54	91.57	82.27	88.80
Caseinogen, . .	2.40	3.98	3.00	1.09	6.10	2.19
Lactalbumin, . .	0.57	0.77	0.62	0.70	1.00	0.42
Fat, ...	2.90	3.50	4.20	1.02	5.30	2.50
Lactose, ...	5.87	4.00	4.00	5.50	4.20	5.50
Salts, ...	0.16	0.17	0.56	0.42	1.00	0.50

Caseinogen is the chief proteid constituent of milk, and is held in solution by the presence of calcic phosphate. On the addition of acetic acid or of sodic chlorid up to the point of saturation, the caseinogen is *precipitated* as such, and may be collected by appropriate chemic methods. When taken into the stomach caseinogen is *coagulated*, that is, it is separated into casein or tyrein and a small quantity of a new soluble proteid. The ferment which induces this change is known as rennin. The presence of calcic phosphate is necessary for this coagulation.

The Fat of milk is more or less solid at ordinary temperatures. It is a composition of olein, palmitin, and stearin, with a small quantity of butyrin and caproin. When milk is allowed to stand for some time the fat globules rise to the surface and form a thick layer known as cream. When subjected to the churning process, the fat globules run together and form a coherent mass—the butter.

Lactose is the particular form of sugar characteristic of milk. It belongs to the saccharose group and has the following composition: $C_{12}H_{22}O_{11}$. In the presence of the Bacillus acidi lactici the lactose is decomposed into lactic acid and carbon dioxid, the former of which will cause a coagulation of the caseinogen.

Mechanism of Secretion.—During the time of lactation the mammary gland exhibits periods of secretory activity which alternate with periods of rest. Coincidently with these periods, certain histologic changes take place in the secreting structures of the gland. At the close of a period of active secretion each acinus presents the following features: The epithelial cells are short, cubical, nucleated, and border a relatively wide lumen in which is to be found a variable quantity of nondischarged milk. After the gland has rested for some time active metabolism again begins. The epithelial cells grow and elongate; the nucleus divides into two or three new nuclei, and at the same time the cell becomes constricted; the inner portion is detached and is discharged into the lumen. Coincidently with these changes oil globules make their appearance in the cell protoplasm, some of which are discharged separately into the lumen, while others remain for a time associated with the detached cell. From these histologic changes it would appear that the caseinogen and the fat globules are metabolic products of the cell protoplasm and not derived directly from the blood. That lactose has a similar origin appears certain from the fact that it is not found either in the blood or any other tissue of the body, and that it is formed independently of carbohydrate food. The water and inorganic salts are doubtless secreted by a mechanism similar to that of all other secreting glands.

VASCULAR OR DUCTLESS GLANDS.

The Vascular Glands are regarded as possessing the power of acting upon certain elements of the food and aiding the process of sanguinification; of modifying the composition of the blood as it flows through their substance, by some act of secretion.

The vascular glands are the *spleen*, *suprarenal capsules*, *thyroid* and *thymus* glands.

The Spleen is about five inches in length, six ounces in weight, of a dark-bluish color, and situated in the left hypochondriac region. It is covered externally by a reflection of the peritoneum, beneath which is the proper fibrous coat, composed of areolar and elastic tissue and nonstriated muscular fibers. From the inner surface of the fibrous envelope processes or trabeculæ are given off, which penetrate the substance of the gland, forming a network, in the meshes of which is contained the *spleen pulp*. The *splenic artery* divides into a number of branches, some of which, when they become very minute, pass directly into veins, while others terminate in true capillaries.

As the capillary vessels ramify through the substance of the gland, their walls frequently disappear and the blood passes from the arteries into the veins through *lacunæ*.

The *splenic* or *Malpighian corpuscles* are small bodies, spherical or ovoid in shape, the $\frac{1}{40}$th of an inch in diameter, situated upon the sheaths of the small arteries. They consist of a delicate membrane containing a semifluid substance composed of numerous small cells resembling lymph corpuscles. The *spleen pulp* is a dark-red, semifluid substance, of a soft consistence, contained in the meshes of the trabeculæ. In it are found numerous corpuscles, like those observed in the Malpighian bodies, blood-corpuscles in a natural and altered condition, nuclei, and pigment-granules.

Function of the Spleen.—Probably influences the preparation of the albuminous food for nutrition; during digestion the spleen becomes larger, its contents are increased in amount, and after digestion it gradually diminishes in size, returning to the normal condition.

The *red corpuscles* are here disintegrated, after having fulfilled their function in the blood, the splenic venous blood containing relatively a small quantity.

The *white corpuscles* appear to be increased in number, the blood of the splenic vein containing an unusually large proportion.

The *spleen* serves also as a reservoir for blood when the portal circulation becomes obstructed.

The *nervous system* controls the enlargement of the spleen; division of the nerve produces dilatation of the vessels, stimulation contracts them.

The Suprarenal Capsules are triangular, flattened bodies, situated above the kidney. They are invested by a fibrous capsule sending in trabeculæ, forming the framework. The glandular tissue is composed of two portions, a *cortical* and *medullary*. The cortical is made up of small cylinders lined by cells and containing an opaque mass, nuclei, and granular matter. The medullary consists of a fibrous network containing in the alveoli nucleated protoplasm.

The Thyroid Gland consists of a fibrous stroma, containing ovoid closed sacs, measuring on the average $\frac{1}{40}$th of an inch, formed of a delicate membrane lined by cells; the contents of the sacs consist of yellowish albuminous fluid.

The Thymus Gland is most developed in early life and almost disappears in the adult. It is divided by processes of fibrous tissue into lobules, and these again into follicles which contain lymphoid corpuscles.

The *functions* of the vascular organs appear to be the more complete elaboration of the blood necessary for proper nutrition; they are most highly developed during infancy and embryonic life, when growth and development are most active.

EXCRETION.

The Principal Excrementitious Fluids discharged from the body are the urine, perspiration, and bile; they hold in solution principles of waste which are generated during the activity of the nutritive process, and are the ultimate forms to which the organic constituents are reduced in the body. They also contain inorganic salts.

The Urinary Apparatus consists of the kidneys, ureters, and bladder.

KIDNEYS.

The Kidneys are the organs for the secretion of urine; they resemble a bean in shape, are from four to five inches in length, two in breadth, and weigh from four to six ounces.

They are situated in the lumbar region, one on each side of the vertebral column behind the peritoneum, and extend from the 11th rib to the crest of the ilium; the anterior surface is convex, the posterior surface concave, the latter presenting a deep notch, the *hilus*.

The kidney is surrounded by a thin, smooth membrane composed of white fibrous and yellow elastic tissue; though it is attached to the surface

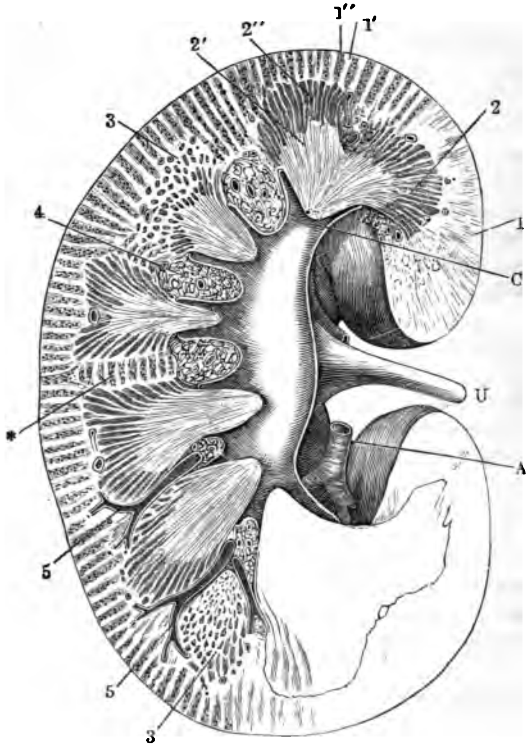

FIG. 14.—LONGITUDINAL SECTION THROUGH THE KIDNEY, THE PELVIS OF THE KIDNEY, AND A NUMBER OF RENAL CALYCES.

A. Branch of the renal artery. U. Ureter. C. Renal calyx. 1. Cortex. 1'. Medullary rays. 1''. Labyrinth, or cortex proper. 2. Medulla. 2'. Papillary portion of medulla, or medulla proper. 2''. Border layer of the medulla. 3, 3. Transverse section through the axes of the tubules of the border layer. 4. Fat of the renal sinus. 5, 5. Arterial branches. *. Transversely coursing medulla rays.—(*Tyson, after Henle.*)

of the kidney by minute processes of connective tissue, it can be readily torn away. The substance of the kidney is dense but friable.

Upon making a longitudinal section of the kidney it will be observed

that the *hilus* extends into the interior of the organ and expands to form a cavity known as the *sinus*. This cavity is occupied by the upper dilated portion of the ureter, the interior of which forms the *pelvis*. The ureter subdivides into several portions, which ultimately give origin to a number of smaller tubes termed *calyces*, which receive the apices of the pyramids.

The Parenchyma of the Kidney consists of two portions, viz.:—

1. *An internal* or *medullary portion*, consisting of a series of *pyramids* or *cones*, some twelve or fifteen in number. They present a distinctly striated appearance, a condition due to the straight direction of the tubules and blood-vessels.
2. *An external* or *cortical portion*, consisting of a delicate matrix containing an immense number of tubules having a markedly convoluted appearance. Throughout its structure are found numerous small ovoid bodies termed *Malpighian corpuscles*.

FIG. 15.—DIAGRAMMATIC EXPOSITION OF THE METHOD IN WHICH THE URINIFEROUS TUBES UNITE TO FORM PRIMITIVE CONES.—(*Tyson, after Ludwig.*)

The Uriniferous Tubules.—The kidney is a compound tubular gland composed of microscopic tubules, whose function it is to secrete from the blood those waste products which collectively constitute the urine. If the apex of each pyramid be examined with a lens, it will present a number of small orifices which are the beginnings of the uriniferous tubules. From this point the tubules pass outward in a straight but somewhat diverging manner toward the cortex, giving off at acute angles a number of branches (Fig. 15). From the apex to the base of the pyramids they are known as the tubules of Bellini. In the cortical portion of the kidney each tubule becomes enlarged and twisted, and after pursuing an extremely convoluted course, turns backward into the medullary portion for some distance, forming the descending limb of Henle's loop; it then turns upon itself, forming the ascending limb of the loop, reenters the cortex, again expands, and finally terminates in a spherical enlargement known as *Müller's* or *Bowman's capsule*. Within this capsule is contained a small tuft of blood-vessels constituting the *glomerulus*, or *Malpighian corpuscle*.

Structure of the Tubules.—Each tubule consists of a basement mem-

brane lined by epithelial cells throughout its entire extent. The tubule and its contained epithelium vary in shape and size in different parts of its course. The termination of the convoluted tube consists of a little sac or capsule, which is ovoidal in shape and measures about $\frac{1}{200}$th of an inch in size. This capsule is lined by a layer of flattened epithelial cells, which is also reflected over the surface of the glomerulus. During the periods of secretory activity, the blood-vessels of the glomerulus become filled with blood, so that the cavity of the sac is almost obliterated; after secretory activity the blood-vessels contract and the sac cavity becomes enlarged. In that portion of the tubule lying between the capsule and Henle's loop the epithelial cells are cuboidal in shape; in Henle's loop they are flattened, while in the remainder of the tubule they are cuboidal and columnar.

Blood-Vessels of the Kidney.—*The renal artery* is of large size and enters the organ at the hilum; it divides into several large branches, which penetrate the substance of the kidney between the pyramids, at the base of which they form an anastomosing plexus, which completely surrounds them. From this plexus vessels follow the straight tubes toward the apex, while others, entering the cortical portion, divide into small twigs, which enter the Malpighian body and form a mass of convoluted vessels, the *glomerulus*. After circulating through the Malpighian tuft, the blood is gathered together by two or three small veins, which again subdivide and form a fine capillary plexus, which envelops the convoluted tubules; from this plexus the veins converge to form the emulgent vein, which empties into the vena cava.

The Nerves of the Kidney follow the course of the blood-vessels and are derived from the renal plexus.

The Ureter is a membranous tube, situated behind the peritoneum, about the diameter of a goose-quill, 18 inches in length, and extends from the pelvis of the kidney to the base of the bladder, which it perforates in an oblique direction. It is composed of three coats, fibrous, muscular, and mucous.

The Bladder is a reservoir for the temporary reception of the urine prior to its expulsion from the body; when fully distended it is ovoid in shape, and holds about *one pint*. It is composed of four coats, *serous*, *muscular*, the fibers of which are arranged longitudinally and circularly, *areolar*, and *mucous*. The orifice of the bladder is controlled by the *sphincter vesicæ*, a muscular band about half an inch in width.

As soon as the Urine is formed it passes through the *tubuli uriniferi*

into the pelvis, and from thence through the ureters into the bladder, which it enters at an irregular rate. Shortly after a meal, after the ingestion of large quantities of fluid, and after exercise, the urine flows into the bladder quite rapidly, while it is reduced to a few drops during the intervals of digestion. It is prevented from regurgitating into the ureters on account of the oblique direction they take between the mucous and muscular coats.

Nervous Mechanism of Urination.—When the urine has passed into the bladder, it is there retained by the sphincter vesicæ muscle, kept in a state of tonic contraction by the action of a nerve center in the lumbar region of the spinal cord. This center can be inhibited and the sphincter relaxed, either *reflexly*, by impressions coming through sensory nerves from the mucous membrane of the bladder, or *directly*, by a voluntary impulse descending the spinal cord. When the desire to urinate is experienced, impressions made upon the vesical sensory nerves are carried to the centers governing the *sphincter* and *detrusor urinæ* muscles and to the brain. If now the act of urination is to take place, a voluntary impulse originating in the brain passes down the spinal cord, and still further inhibits the sphincter vesicæ center, with the effect of relaxing the muscle, and of stimulating the center governing the detrusor muscle, with the effect of contracting the muscle and expelling the urine. If the act is to be suppressed, voluntary impulses inhibit the *detrusor* center and possibly stimulate the *sphincter* center.

The *genitospinal* center controlling these movements is situated in that portion of the spinal cord corresponding to the origin of the 3d, 4th, and 5th sacral nerves.

URINE.

Normal Urine is of a pale yellow or amber color, perfectly transparent, with an aromatic odor, an acid reaction, a specific gravity of 1.020, and a temperature when first discharged of 100° Fahr.

The *color* varies considerably in health, from a pale yellow to a brown hue due to the presence of the coloring matter, *urobilin* or *urochrome.*

The *transparency* is diminished by the presence of mucus, the calcium and magnesium phosphates, and the mixed urates.

The *reaction* of the urine is acid, owing to the presence of acid phosphate of sodium. The degree of acidity, however, varies at different periods of the day. Urine passed in the morning is strongly acid, while that passed during and after digestion, especially if the food is largely vegetable in character, is either neutral or alkaline.

The *specific gravity* varies from 1.015 to 1.025.

The *quantity* of urine excreted in twenty-four hours is between 40 and 50 fluidounces, but ranges above and below this standard.

The *odor* is characteristic, and caused by the presence of taurylic and phenylic acids, but is influenced by vegetable foods and other substances eliminated by the kidneys.

COMPOSITION OF URINE.

Water,	967.
Urea,	14.230
Other nitrogenized crystalline bodies, uric acid, principally in the form of alkaline urates, Creatin, creatinin, xanthin, hypoxanthin, Hippuric acid, leucin, tyrosin, taurin, cystin, all in small amounts, and not constant, Mucus and pigment,	10.635
Salts :—	
Inorganic: principally sodium and potassium sulphates, phosphates, and chlorids, with magnesium and calcium phosphates, traces of silicates and chlorids, *Organic:* lactates, hippurates, acetates, formates, which appear only occasionally,	8.135
Sugar,	a trace.
Gases (nitrogen and carbonic acid principally).	
	1000.00

The Average Quantity of the principal constituents excreted in twenty-four hours is as follows :—

Water,	52.	fluidozs.
Urea,	512.4	grains.
Uric acid,	8.5	"
Phosphoric acid,	45.0	"
Sulphuric acid,	31.11	"
Inorganic salts,	323.25	"
Lime and magnesia,	6.5	"

To Determine the Amount of solid matters in any given amount of urine, multiply the last two figures of the specific gravity by the co-efficient of Hæser, 2.33; *e. g.*, in 1000 grains of urine having a specific gravity 1.022, there are contained $22 \times 2.33 = 51.26$ grains of solid matter.

Organic Constituents of Urine.—Urea is one of the most important of the organic constituents of the urine, and is present to the extent of from 2.5 to 3.2 per cent. Urea is a colorless, neutral substance, crystallizing to four-sided prisms terminated by oblique surfaces. When crystalliza-

tion is caused to take place rapidly, the crystals take the form of long, silky needles. Urea is soluble in water and alcohol; when subjected to prolonged boiling it is decomposed, giving rise to carbonate of ammonia. In the alkaline fermentation of urine, uıea takes up two molecules of water with the production of carbonate of ammonia.

The *average amount* of urea excreted daily has been estimated at about 500 grains. As urea is one of the principal products of the breaking up of the albuminous compounds within the body, it is quite evident that the quantity produced and eliminated in twenty-four hours will be *increased* by any increase in the amount of albuminous food consumed, by a rapid destruction of albuminous tissues, as is witnessed in various pathologic states, inanition, febrile conditions, fevers, etc. A farinaceous or vegetable diet will diminish the urea production nearly one-half.

Muscular exercise when the nutrition of the body is in a state of equilibrium does not seem to increase the quantity of urea.

Seat of Urea Formation.—As to the seat of urea formation, little is positively known. It is quite certain that it preexists in the blood and is merely excreted by the kidneys. It is not produced in muscles, as even after prolonged exercise hardly a trace of urea is to be found in them. Experimental and pathologic facts point to the liver as the probable organ engaged in urea formation. Acute yellow atrophy of the liver, suppurative diseases of the liver, diminish almost entirely the production of urea.

Uric Acid is also a constant ingredient of the urine and is closely allied to urea. It is a nitrogenized substance, carrying out of the body a large quantity of nitrogen. The amount eliminated daily varies from five to ten grains. Uric acid is a colorless crystal belonging to the rhombic system. It is insoluble in water, and if eliminated in excessive amounts it is deposited as a "brick red" sediment in the urine. It is doubtful if uric acid exists in a free state, being combined for the most part with sodium and potassium bases forming urates. It is to be regarded as one of the terminal products of the disassimilation of albuminous compounds, and is probably produced in the liver.

Hippuric Acid is found very generally in urine, though it is present only in small amounts. It is increased by a diet of asparagus, cranberries, plums, and by the administration of benzoic and cinnamic acids. It is probably formed in the kidney.

Kreatinin resembles the kreatin derived from muscles. It is a colorless crystal, belonging to the rhombic system. Its origin is unknown, though it is largely increased in amount by albuminous food. About 15 grains are excreted daily.

Xanthin, Sarkin, Oxaluric Acid, and Allantoin are also constituents of urine. They are nitrogenized compounds and are also terminal products of albuminous compounds.

Urobilin, the coloring matter of the urine, is a derivative of the bile pigments. It is particularly abundant in febrile conditions, giving to the urine its reddish-yellow color.

Inorganic Constituents of Urine.—Earthy Phosphate. *Phosphoric acid* in combination with magnesium and calcium is excreted daily to the extent of from 15 to 30 grains. The phosphates are insoluble in water, but are held in solution in the urine by its acid ingredients, alkalinity of the urine being attended with a copious precipitation of the phosphates. Mental work increases the amount of phosphoric acid excreted, a condition caused by increased metabolism of the nervous tissue.

Sulphuric acid in combination with sodium and potassium constitute the sulphates, of which about 30 grains are excreted daily. Sulphuric acid results largely from the decomposition of albuminous food and from increased destruction of animal tissues.

The *Gases* of urine are carbonic acid and nitrogen.

Mechanism of Urinary Secretion.—As the kidney anatomically presents an apparatus for filtration (the Malpighian bodies) and an apparatus for secretion (the epithelial cells of the urinary tubules), it might be inferred that the elimination of the constituents of the urine is accomplished by the twofold process of *filtration* and *secretion*; that the water and highly diffusible inorganic salts simply pass by diffusion through the walls of the blood-vessels of the glomerulus into the capsule of Müller, while the urea and remaining organic constituents are removed by true secretory action of the renal epithelium. Modern experimentation supports this view of renal action.

The secretion of urine is therefore partly *physical* and partly *vital*.

The *filtration* of urinary constituents from the glomerulus into Müller's capsule depends largely upon the blood pressure and the rapidity of blood flow in the renal artery and glomerulus. Among the influences which increase the pressure and velocity may be mentioned increased frequency and force of the heart's action, contraction of the capillary vessels of the body generally, dilatation of the renal artery, increase in the volume of the blood.

The reverse conditions lower the blood pressure and diminish the secretion of urine.

The elimination of the organic matters by *secretory activity* of the renal

epithelium seems to be well established by modern experiments. These substances, removed from the blood in the secondary capillary plexus of blood-vessels, by a true selective action of the epithelium, are dissolved and washed toward the pelves by the liquid coming from the capsules.

The blood supply to the kidney is regulated by the nervous system. If the renal nerves be divided, the renal artery dilates and a copious flow of urine takes place. If the peripheral ends of the same nerves be stimulated, the artery contracts and the urinary flow ceases. The same is true of the splanchnic nerves, through which the vasomotor nerves coming from the medulla oblongata and spinal cord pass to the renal plexus.

LIVER.

The Liver is a highly vascular, conglomerate gland, appended to the alimentary canal. It is the largest gland in the body, weighing about four and one-half pounds; it is situated in the right hypochondriac region, and retained in position by five ligaments, four of which are formed by duplicatures of the peritoneal investment.

The *proper coat* of the liver is a thin but firm fibrous membrane, closely adherent to the surface of the organ, which it penetrates at the transverse fissure, and follows the vessels in their ramifications through its substance, constituting *Glisson's capsule.*

Structure of the Liver.—The liver is made up of a large number of small bodies, *the lobules*, rounded or ovoid in shape, measuring the $\frac{1}{25}$th of an inch in diameter, separated by a space in which are situated blood-vessels, nerves, hepatic ducts, and lymphatics.

The Lobules are composed of cells, which, when examined microscopically, exhibit a rounded or polygonal shape, and measure, on the average, the $\frac{1}{1000}$th of an inch in diameter; they possess one, and at times two, nuclei; they also contain globules of fat, pigment matter, and animal starch. The cells constitute the *secreting* structure of the liver, and are the *true hepatic cells.*

The Blood-vessels which enter the liver are—

1. The *portal vein*, made up of the *gastric*, *splenic*, *superior*, and *inferior mesenteric veins.*
2. The *hepatic artery*, a branch of the celiac axis, both of which are invested by a sheath of areolar tissue; the vessels which leave the liver are the *hepatic veins*, originating in its interior, collecting the blood distrib-

uted by the portal vein and hepatic artery, and conducting it to the *ascending vena cava*.

Distribution of Vessels.—The *portal vein* and *hepatic artery*, upon entering the liver, penetrate its substance, divide into smaller and smaller branches, occupy the spaces between the lobules, completely surrounding and limiting them, and constitute the *interlobular* vessels. The *hepatic artery*, in its course, gives off branches to the walls of the portal vein and Glisson's capsule, and finally empties into the small branches of the *portal vein* in the interlobular spaces.

The *interlobular vessels* form a rich plexus around the lobules, from which branches pass to neighboring lobules and enter their substance, where they form a very fine network of capillary vessels, ramifying over the hepatic cells, in which the various functions of the liver are performed. The blood is then collected by small veins, converging toward the center of the lobule, to form the *intralobular vein*, which runs through its long axis and empties into the *sublobular vein*. The *hepatic veins* are formed by the union of the sublobular veins, and carry the blood to the ascending vena cava; their walls are thin and adherent to the substance of the hepatic tissue.

The Hepatic Ducts or Bile Capillaries originate within the lobules, in a very fine plexus lying between the hepatic cells; whether the smallest vessels have distinct membranous walls, or whether they originate in the spaces between the cells by open orifices, has not been satisfactorily determined.

The *Bile Channels* empty into the interlobular ducts, which measure about $\frac{1}{2000}$th of an inch in diameter, and are composed of a thin, homogeneous membrane lined by flattened epithelial cells.

As the interlobular bile ducts unite to form larger trunks, they receive an external coat of fibrous tissue, which strengthens their walls; they finally unite to form one large duct, the *hepatic duct*, which joins the *cystic duct*; the union of the two forms the *ductus communis choledochus*, which is about three inches in length, the size of a goose quill, and opens into the duodenum.

The Gall Bladder is a pear-shaped sac, about four inches in length, situated in a fossa on the under surface of the liver. It is a reservoir for the bile, and is capable of holding about one ounce and a half of fluid. It is composed of three coats,—

1. Serous, a reflection of the peritoneum.
2. Fibrous and muscular.
3. Mucous.

Functions of the Liver.—The liver is a complex organ having a variety of relations to the general processes of the body. While its physiologic actions are not yet wholly understood, it may be said that it—

1. Secretes bile.
2. Forms glycogen.
3. Assists in the formation of urea and allied products.
4. Modifies the composition of the blood as it passes through it.

The Secretion of Bile.—The characteristic constituents of the bile do not preexist in the blood, but are formed within the interior of the liver cells out of materials derived from the venous and arterial blood. The hepatic cells absorbing these materials elaborate them into bile elements, and in so doing undergo histologic changes similar to those exhibited by other secretory glands. The bile once formed, it passes into the mouths of the bile capillaries, near the periphery of the lobules. Under the influence of the vis a-tergo of the new-formed bile it flows from the smaller into the larger bile ducts, and finally empties into the intestine, or is regurgitated into the gall bladder, where it is stored up until it is required for the digestive process in the small intestine. The study of the secretion of bile by means of biliary fistulæ reveals the fact that the secretion is continuous and not intermittent; that the hepatic cells are constantly pouring bile into the ducts, which convey it into the gall bladder. As this fluid is required only during intestinal digestion, it is only then that the walls of the gall bladder contract and discharge it into the intestine.

The flow of bile from the liver cells into the gall bladder is accomplished by the inspiratory movements of the diaphragm, the contraction of the muscular fibers of the biliary ducts, as well as the vis-a tergo of new-formed bile. Any obstacle to the outflow of bile into the intestine leads to an accumulation within the bile ducts. The pressure within the ducts increasing beyond that of the blood within the capillaries, a re-absorption of biliary matters by the lymphatics takes place, giving rise to the phenomena of jaundice.

The Bile is both a *secretion* and an *excretion;* it contains new constituents which are formed only in the substance of the liver, and are destined to play an important part ultimately in nutrition; it contains also waste ingredients which are discharged into the intestinal canal and eliminated from the body.

Glycogenic Function.—In addition to the preceding function, Bernard, in 1848, demonstrated the fact that the liver, during life, normally produces a sugar-forming substance, analogous in its chemical composition to starch,

which he terms glycogen; also that when the liver is removed from the body, and its blood-vessels thoroughly washed out, after a few hours sugar again makes its appearance in abundance.

It can be shown to exist in the blood of the hepatic vein as well as in a decoction of the liver substance by means of either Trommer's or Fehling's tests, even when the blood of the portal vein does not contain a trace of sugar.

Origin and Destination of Glycogen.—Glycogen appears to be formed *de novo* in the liver cells, from materials derived from the food, whether the diet be animal or vegetable, though a larger per cent. is formed when the animal is fed on starchy and saccharin, than when fed on animal food. The *glucose*, which is one of the products of digestion, is absorbed by the blood-vessels, and carried directly into the liver; as it does not appear in the urine, as it would if injected at once into the general circulation, it is probable that it is detained in the liver, dehydrated, and stored up as *glycogen*. The change is shown by the following formula:—

$$\underset{\text{Glucose.}}{C_6H_{12}O_6} - \underset{\text{Water.}}{H_2O} = \underset{\text{Glycogen.}}{C_6H_{10}O_5}.$$

The glycogen thus formed is stored up in the hepatic cells for the future requirements of the system. When it is carried from the liver it is again transformed into *glucose* by the agency of a ferment. Glycogen does not undergo oxidation in the blood; this takes place in the tissues, particularly in the muscles, where it generates heat and contributes to the development of muscular force.

Glycogen, when obtained from the liver, is an amorphous, starch-like substance, of a white color, tasteless and colorless, and soluble in water; by boiling with dilute acids, or subjected to the action of an animal ferment, it is easily converted into *glucose*. When an excess of sugar is generated by the liver, it can be found, not only in the blood of the hepatic vein, but also in other portions of the body; under these circumstances it is eliminated by the kidneys, appearing in the urine, constituting the condition of *glycosuria*.

Formation of Urea.—The liver is now regarded by many physiologists to be the principal organ concerned in urea formation. The liver normally contains a certain amount of urea, and if blood be passed through the excised liver of an animal which has been in full digestion, a large amount of urea is obtained. The clinical evidence proves that in destructive diseases of the liver substance there is at once a falling off in urea elimination. Various drugs which increase liver action increase the urea in the urine.

Elaboration of Blood.—Besides the capability of secreting bile, the liver posesses the property of so acting upon and modifying the chemic composition of the products of digestion as they traverse its substance, that they readily assimilate with the blood, and are transformed into materials capable of being converted into the elements of the blood and solid tissues.

The *albuminous* particularly requires the modifying influence of the liver; for if it be removed from the portal vein and introduced into the jugular vein, it is at once removed from the blood by the action of the kidneys.

The blood of the *hepatic vein* differs from the blood of the *portal vein* in being richer in blood corpuscles, both red and white; its plasma is more dense, containing a less percentage of water and a greater amount of solid constituents, but no fibrin; its serum contains less albumin, fats, and salts, but its sugar is increased.

Influence of the Nervous System.—The nervous system directly controls the functional activity of the liver, and more especially its glycogenic function. It was discovered by Bernard that puncture of the medulla oblongata is followed by such an enormous production of sugar that it is at once excreted by the kidneys, giving rise to diabetic or saccharin urine. This part of the medulla is, however, the vasomotor center for the blood-vessels of the liver. Destruction of this center, or injury to the vasomotor nerves emanating from it in any part of their course, is followed at once by dilatation of the hepatic blood-vessels, slowing of the blood current, a profound disturbance of the normal relation existing between the blood and liver cells, and a production of sugar. Many of the hepatic vasomotor nerves may be traced down the cord as far as the lumbar region, while others leave the cord high up in the neck and enter the cervical ganglia of the sympathetic and so reach the liver. Injury to the sympathetic ganglia is often followed by diabetes. Peripheral stimulation of various nerves, *e. g.*, sciatic, pneumogastric, depressor nerve, as well as the direct action of many drugs, impair or depress the hepatic vasomotor center and so give rise to diabetes.

SKIN.

The Skin, the external investment of the body, is a most complex and important structure, serving—

1. As a *protective covering.*
2. An organ for *tactile sensibility.*
3. An organ for the *elimination of excrementitious matters.*

The Amount of Skin investing the body of a man of average size is about twenty feet, and varies in thickness, in different situations, from the $\frac{1}{8}$th to the $\frac{1}{100}$th of an inch.

The skin consists of two principal layers, viz., a deeper portion, the *Corium*, and a superficial portion, the *Epidermis*.

The Corium, or Cutis vera, may be subdivided into a *reticulated* and a *papillary* layer. The *former* is composed of white fibrous tissue, non-striated muscular fibers, and elastic tissue, interwoven in every direction, forming an areolar network, in the meshes of which are deposited masses of fat, and a structureless amorphous matter; the *latter* is formed mainly of club-shaped elevations or projections of the amorphous matter, constituting the *papillæ;* they are most abundant, and well developed, upon the palms of the hands and the soles of the feet; they average the $\frac{1}{100}$th of an inch in length, and may be simple or compound; they are well supplied with nerves, blood-vessels, and lymphatics.

The Epidermis, or Scarf Skin, is an extravascular structure, a product of the true skin, and composed of several layers of cells. It may be divided into two layers, the *rete mucosum*, or the *Malpighian layer*, and the *horny* or *corneous*.

The *former* closely applies itself to the papillary layer of the true skin, and is composed of large, nucleated cells, the lowest layer of which, the "prickle cells," contain pigment granules, which give to the skin its varying tints in different individuals and in different races of men; the more superficial cells are large, colorless, and semitransparent. The *latter*, the corneous layer, is composed of flattened cells, which, from their exposure to the atmosphere, are hard and horny in texture; it varies in thickness from $\frac{1}{8}$th of an inch on the palms of the hands and feet, to the $\frac{1}{900}$th of an inch in the external auditory canal.

APPENDAGES OF THE SKIN.

Hairs are found in almost all portions of the body, and can be divided into—

1. Long, soft hairs, on the head.
2. Short, stiff hairs, along the edges of the eyelids and nostrils.
3. Soft, downy hairs, on the general cutaneous surface. They consist of a *root* and a *shaft*, which is oval in shape, and about the $\frac{1}{400}$th of an inch in diameter; it consists of fibrous tissue, covered externally by a layer of imbricated cells, and internally by cells containing granular and pigment material.

The *Root* of the hair is embedded in the hair follicle, formed by a tubular depression of the skin, extending nearly through to the subcutaneous tissue; its walls are formed by the layers of the corium, covered by epidermic cells. At the bottom of the follicle is a papillary projection of amorphous matter, corresponding to a papilla of the true skin, containing blood-vessels and nerves, upon which the hair root rests. The investments of the hair roots are formed of epithelial cells, constituting the *internal* and *external* root sheaths.

The hair protects the head from the heat of the sun and cold, retains the heat of the body, prevents the entrance of foreign matter into the lungs, nose, ears, etc. The *color* is due to the pigment matter, which, in old age, becomes more or less whitened.

The Sebaceous Glands, imbedded in the true skin, are simple and compound racemose glands, opening, by a common excretory duct, upon the surface of the epidermis or into the hair follicle. They are found in all portions of the body, most abundantly in the face, and are formed by a delicate, structureless membrane, lined by flattened polyhedral cells. The sebaceous glands secrete a peculiar oily matter, the *sebum*, by which the skin is lubricated and the hairs softened; it is quite abundant in the region of the nose and forehead, which often present a greasy, glistening appearance; it consists of water, mineral salts, fatty globules, and epithelial cells.

The *vernix caseosa*, which frequently covers the surface of the fetus at birth, consists of the residue of the sebaceous matters, containing epithelial cells and fatty matters; it seems to keep the skin soft and supple, and guards it from the effects of the long-continued action of water.

The Sudoriparous Glands excrete the sweat. They consist of a mass or coil of a tubular gland duct, situated in the derma and in the subcutaneous tissue, average the $\frac{1}{75}$th of an inch in diameter, and are surrounded by a rich plexus of capillary blood-vessels. From this coil the duct passes in a straight direction up through the skin to the epidermis, where it makes a few spiral turns and opens obliquely upon the surface. The sweat glands consist of a delicate homogeneous membrane lined by epithelial cells, whose function is to extract from the blood the elements existing in the perspiration.

The glands are very abundant all over the cutaneous surface, as many as 3528 to the square inch, according to Erasmus Wilson.

The Perspiration is an excrementitious fluid, clear, colorless, almost odorless, slightly acid in reaction, with a specific gravity of 1.003 to 1.004.

The Total Quantity of perspiration excreted daily has been estimated

at about two pounds, though the amount varies with the nature of the food and drink, exercise, external temperature, season, etc.

The elimination of the sweat is not intermittent, but continuous; but it takes place so gradually that as fast as it is formed it passes off by evaporation as *insensible* perspiration. Under exposure to great heat and exercise the evaporation is not sufficiently rapid, and it appears as *sensible* perspiration.

COMPOSITION OF SWEAT.

Water,	995.573
Urea,	0.043
Fatty matters,	0.014
Alkaline lactates,	0.317
Alkaline sudorates,	1.562
Inorganic salts,	2.491
	1000.00

Urea is a constant ingredient.

Carbonic acid is also exhaled from the skin, the amount being about $\frac{1}{200}$th of that from the lungs.

Perspiration regulates the temperature and removes waste matters from the blood; it is so important, that if elimination be prevented death occurs in a short time.

Influence of the Nervous System.—The secretion of sweat is regulated by the nervous system. Here, as in the secreting glands, the fluid is formed from material in the lymph spaces surrounding the gland. Two sets of nerves are concerned, viz., *vasomotor*, regulating the blood supply; and *secretory*, stimulating the activities of the gland cells. Generally the two conditions, increased blood flow and increased glandular action, co-exist. At times profuse clammy perspiration occurs, with diminished blood flow.

The dominating sweat center is located in the medulla, though subordinate centers are present in the cord. The secretory fibers reach the perspiratory glands of the head and face through the cervical sympathetic; of the arms, through the thoracic sympathetic, ulnar, and radial nerves; of the leg, through the abdominal sympathetic and sciatic nerves.

The sweat center is excited to action by mental emotions, increased temperature of blood circulating in the medulla and cord, increased venosity of blood, and many drugs, rise of external temperature, exercise, etc.

CEREBROSPINAL AXIS.

The Cerebrospinal Axis consists of the spinal cord, medulla oblongata, pons Varolii, cerebellum and cerebrum, exclusive of the spinal and cranial nerves. It is contained within the cavities of the cranium and spinal column, and surrounded by three membranes, the dura mater, arachnoid, and pia mater, which protect it from injury and supply it with blood-vessels.

MEMBRANES.

The Dura Mater, the most external of the three, is a tough membrane, composed of white fibrous tissue, arranged in bundles, which interlace in every direction. In the cranial cavity it lines the inner surface of the bones, and is attached to the edge of the foramen magnum; sends processes inward, forming the falx cerebri, falx cerebelli, and tentorium cerebelli, supporting and protecting parts of the brain. In the spinal canal it loosely invests the cord, and is separated from the walls of the canal by areolar tissue.

The Arachnoid, the middle membrane, is a delicate serous structure which envelopes the brain and cord, forming the *visceral layer*, and is then reflected to the inner surface of the dura mater, forming the *parietal layer*. Between the two layers there is a small quantity of fluid which prevents friction by lubricating the two surfaces.

The Pia Mater, the most internal of the three, composed of areolar tissue and blood-vessels, covers the entire surface of the brain and cord, to which it is closely adherent, dipping down between the convolutions and fissures. It is exceedingly vascular, sending small blood-vessels some distance into the brain and cord.

The Cerebrospinal Fluid occupies the *subarachnoid space* and the general ventricular cavities of the brain, which communicate by an opening, the foramen of Magendie, in the pia mater, at the lower portion of the 4th ventricle. This fluid is clear, transparent, alkaline, possesses a salt taste and a low specific gravity; it is composed largely of water, traces of albumin, glucose, and mineral salts. It is secreted by the pia mater; the quantity is estimated from two to four fluidounces.

The *function* of the cerebrospinal fluid is to protect the brain and cord by preventing concussion from without; by being easily displaced into the spinal canal, prevents undue pressure and insufficiency of blood to the brain.

SPINAL CORD.

The Spinal Cord varies from 16 to 18 inches in length; is half an inch in thickness, weighs 1½ ozs., and extends from the atlas to the 2d lumbar vertebra, terminating in the *filum terminale*. It is cylindrical in shape, and presents an enlargement in the lower cervical and lower dorsal regions, corresponding to the origin of the nerves which are distributed to the upper and lower extremities. The cord is divided into two lateral halves by the anterior and posterior fissures. It is composed of both *white* or *fibrous* and *gray* or *vesicular* matter, the former occupying the exterior of the cord, the latter the interior, where it is arranged in the form of two crescents, one in each lateral half, united together by the central mass, the *gray commissure;* the white matter being united in front by the *white commissure.*

Structure of the Gray Matter.—The gray matter is arranged in the form of two crescents, united by a commissural band, forming a figure resembling the letter H. Each crescent presents an *anterior* and a *posterior* horn. The center of the commissure presents a canal which extends from the fourth ventricle downward to the filum terminale. The anterior horn is short and broad and does not extend to the surface. The posterior horn is narrow and elongated and extends quite to the surface. It is covered and capped by the *substantia gelatinosa*. The gray matter consists primarily of a framework of fine connective tissue, supporting blood-vessels, lymphatics, medullated and non-medullated nerve fibers, and groups of nerve cells.

The Nerve Cells are arranged in groups, which extend for some distance throughout the cord, forming columns more or less continuous. The first group is situated in the anterior horn, the cells of which are large multipolar and connected with the anterior roots of the spinal nerves. The second group is situated in the posterior horn, the cells of which are spindle-shaped, and from their relation to the posterior roots are supposed to be sensory in function. The third group is situated in the lateral aspect of the gray matter, and is quite separate and distinct, except in the lumbar and cervical enlargements, where it blends with those of the anterior horn. A fourth group is situated at the inner base of the posterior horn; it begins about the 7th or 8th cervical nerve and extends downward to the 2d or 3d lumbar, being most prominent in the dorsal region. This column is known as Clark's vesicular column.

Structure of the White Matter.—The white matter surrounding each lateral half of the cord is made up of nerve fibers, some of which are con-

tinuations of the nerves which enter the cord, while others are derived from different sources. It is subdivided into—

1. An *anterior* column, comprising that portion between the anterior roots and the anterior fissure, which is again subdivided into two parts:—
   a. An *inner* portion, bordering the anterior median fissure, the *direct pyramidal tract*, or column of Türck, containing motor fibers which do not decussate, and which extends as far down as the middle of the dorsal region.
   b. An *outer* portion, surrounding the anterior cornua, known as the *anterior root zone*, composed of short, longitudinal fibers which serve to connect together different segments of the spinal cord.

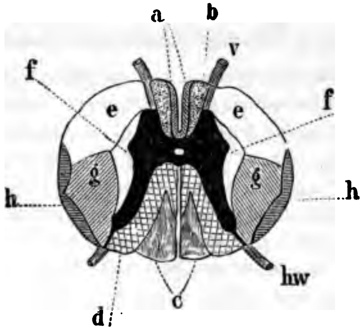

FIG. 16.—SCHEME OF THE CONDUCTING PATHS IN THE SPINAL CORD AT THE 3D DORSAL NERVE.

The black part is the gray matter. v. Anterior, hw, posterior, root. a. Direct, and, g, crossed, pyramidal tracts. b. Anterior column, ground bundle. c. Goll's column. d. Postero-external column. e and f. Mixed lateral paths. h. Direct cerebellar tracts.—(*Landois*.)

2. A *lateral* column, the portion between the anterior and posterior roots, which is divisible into—
   a. The *crossed pyramidal tract*, occupying the posterior portion of the lateral column, and containing all those fibers of the motor tract which have decussated at the medulla oblongata; it is composed of longitudinally running fibers which are connected with the multipolar nerve cells of the anterior cornua.
   b. The *direct cerebellar tract*, situated upon the surface of the lateral column, consisting of longitudinal fibers which terminate in the cerebellum; it first appears in the lumbar region, and increases as it passes upward.
   c. The anterior tract, lying just posterior to the anterior cornua.
3. A *posterior* column, the portion included between the posterior roots and the posterior fissure, also divisible into two portions:—
   a. An *inner* portion, the *postero-internal column*, or the column of Goll, bordering the posterior median fissure, and

b. An *external* portion, the *postero-external column*, the column of Burdach, lying just behind the posterior roots. They are composed of long and short commissural fibers which connect together different segments of the spinal cord.

SPINAL NERVES.

Origin.—The spinal nerves are thirty-one in number on each side of the spinal cord, and arise by two roots, an *anterior* and *posterior*, from the anterior and posterior aspects of the cord respectively; the *posterior roots* present near their emergence from the cord a small ganglionic enlargement; outside of the spinal canal the two roots unite to form a main trunk, which is ultimately distributed to the skin, muscles, and viscera.

The Function of the Anterior Roots is to transmit efferent impulses from the centers to the periphery. Irritation of these roots causes—

1. Convulsive movements in the muscles.
2. Secretion of glands, and
3. Changes in vascular caliber.

Division of these roots is followed by—

1. Loss of muscular movement.
2. Cessation of secretion, and
3. Loss of vascular changes.

The Function of the Posterior Roots is to transmit afferent impulses from the periphery to the spinal cord and brain. Irritation of these roots produces—

1. Reflex activities.
2. Conscious sensations.

Division of these roots is followed by—

1. A loss of reflex activity and
2. By a loss of sensation in all the parts to which they are distributed.

The *ganglion* on the posterior root influences the nutrition of the sensory nerve; for if the nerve be separated from the ganglion, it undergoes degeneration in the course of a few days in the direction in which it carries impressions, *i. e.*, from the periphery to the centers; if the nerve be *divided between* the ganglion and the cord, the central end only undergoes degeneration. The nutrition of the *anterior root* is governed by nerve cells in the gray matter of the cord; for if these cells undergo *atrophy*, or if the nerve be *divided*, it undergoes degeneration outward.

COURSE OF THE ANTERIOR AND POSTERIOR ROOTS.

The Anterior Roots pass through the anterior columns, horizontally, in straight and distinct bundles, and enter the anterior cornuæ, where they diverge in four directions :—

1. Many become connected with the prolongations of the multipolar nerve cells.
2. Others leave the gray matter, pass through the anterior white commissure, and enter the anterior columns of the opposite side.
3. A considerable number enter the *lateral* columns of the same side, through which they pass to the medulla oblongata, where they decussate and finally terminate in the *corpus striatum* of the opposite side.
4. Others traverse the gray matter horizontally, and come into relation with the cells of the intermediary lateral column.

The Posterior Roots enter the posterior horns of the gray matter—

1. Through the substantia gelatinosa.
2. Through the posterior columns; of the *former*, some bend upward and downward, and become connected with the anterior cornuæ; others pass through the posterior commissure to the opposite side; of the *latter*, fibers pass into the gray matter to the posterior vesicular columns, passing obliquely through the posterior white columns upward and downward for some distance, and enter the gray matter at different heights.

Decussation of Motor and Sensory Fibers.—The *Motor* fibers, which conduct volitional impulses from the brain outward to the anterior cornuæ, arise in the motor centers of the cerebrum; they then pass downward through the corona radiata, the internal capsule, the inferior portions of the crura cerebri, the pons Varolii, to the medulla oblongata, where the motor tract of each side divides into two portions, viz.:—

1. The *larger*, containing 91 to 97 per cent. of the fibers, which decussates at the lower border of the medulla and passes down in the *lateral column* of the opposite side, and constitutes the *crossed pyramidal tract*.
2. The *smaller*, containing three to nine per cent. of the fibers, does not decussate, but passes down the *anterior column* of the same side, and constitutes the *direct pyramidal tract*, or the column of Türck. Some of the motor fibers of these two tracts, after entering the anterior cornuæ of the gray matter, become connected with the large multipolar nerve cells, while others pass directly into the anterior roots. Through this decussation each half of the brain governs the muscular movements of the opposite side of the body.

The *Sensory* fibers, which convey the impression made upon the peri-

phery to the cord and brain, pass into the cord through the posterior roots of spinal nerves; they then diverge and enter the gray matter at different levels, and at once decussate, passing to the opposite side of the gray matter. The *sensory tract* passes upward, through the cord, the medulla, pons Varolii, the superior portion of the crura cerebri, the posterior third of the internal capsule, to the sensory perceptive center, located in the hippocampus major and unciate convolution (Ferrier). Through this decussation each half of the brain governs the sensibility of the opposite half of the body.

Properties of the Spinal Cord.—Irritation applied directly to the *anterolateral* white columns produces muscular movements but no pain; they are, therefore, *excitable* but *insensible*.

The surface of the *posterior* columns is not sensitive to direct irritation, except near the origin of the posterior roots. The sensibility is due, however, *not* to its own proper fibers, but to the fibers of the posterior root which traverse it.

Division of the *anterolateral* columns abolishes all power of voluntary movement in the lower extremities.

Division of the *posterior* columns impairs the power of muscular coordination, such as is witnessed in locomotor ataxia.

The *gray matter* is probably both *insensible* and *inexcitable* under the influence of direct stimulation.

A *transverse section* of one lateral half of the cord produces:—

1. On the *same* side, paralysis of voluntary motion and a relative or absolute elevation of temperature and an increased flow of blood in the paralyzed parts; hyperesthesia for the sense of contact, tickling, pain, and temperature.
2. On the *opposite* side, complete anesthesia as regards contact, and tickling and temperature, in the parts corresponding to those which are paralyzed in the opposite side, with a complete preservation of voluntary power and of the muscular sense.

A *vertical* section through the middle of the *gray matter* results in the loss of sensation on both sides of the body below the section, but no loss of voluntary power.

FUNCTIONS OF THE SPINAL CORD.

1. As an Independent Nerve Center.

The spinal cord, in virtue of its contained nerve-cells, is capable of transforming afferent nerve impulses arriving through the afferent nerves

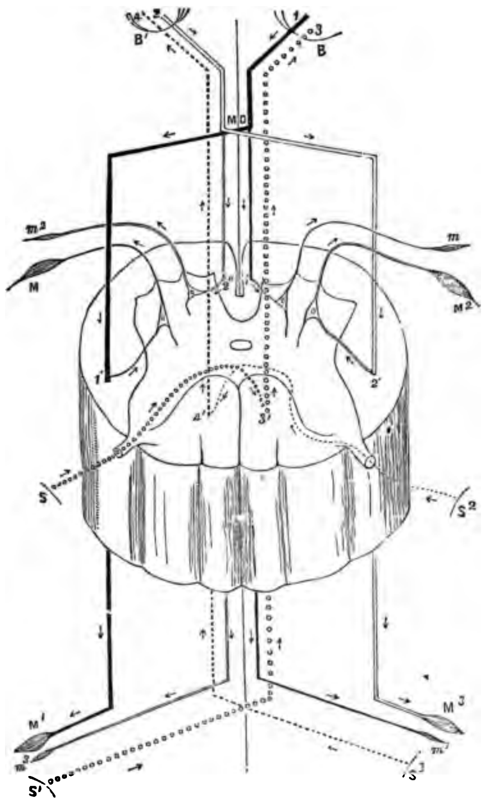

FIG. 17.—DIAGRAM SHOWING THE COURSE, THROUGH THE SPINAL CORD, OF THE MOTOR AND SENSORY NERVE FIBERS.

B and B′ represent the right and left hemispheres of the brain, from which the motor fibers take their origin, and in which the sensory fibers terminate. The *motor tract* from the right side, 1, passes down through the crus, through the pons to the medulla oblongata, where it divides into two portions: 1st, the *larger portion*, 97 per cent., crosses over to the opposite side of the cord and passes down through the lateral column. It gives off fibers at different levels, which pass into the gray matter and become connected with the muscles, M, through the multipolar cells; the *smaller portion*, three per cent., does not cross over, but descends on the same side of the cord in the anterior column and supplies the muscles, *m*. The same is true for the motor tract for the left hemisphere.

The *sensory fibers* from the left side of the body enter the gray matter through the posterior roots. They then cross over at once to the opposite side of the cord and ascend to the hemisphere partly in the gray matter, partly in the posterior column. The same is true for the sensory nerves of the right side of the body.

into efferent impulses, which are reflected outward through efferent nerves to muscles producing motion, to glands exciting secretion, to blood-vessels changing their caliber. All such actions taking place independent of either sensation or volition are termed reflex actions. The mechanism involved in every reflex action consists of a sentient surface, an afferent nerve, a receptive center in connection with the nerve, a commissural fiber, an emissive center, an efferent nerve, and a responsive organ, muscle, gland, or blood-vessel.

The *reflex excitability* of the cord may be—

1. *Increased* by disease of the lateral columns, the administration of strychnia, and, in frogs, by a separation of the cord from the brain, the latter apparently exerting an inhibitory influence over the former and depressing its reflex activity.
2. *Inhibited* by destructive lesions of the cord, *e.g.*, locomotor ataxia, atrophy of the anterior cornuæ, the administration of various drugs, and, in the frog, by irritation of certain regions of the brain. When the cerebrum alone is removed and the optic lobes stimulated, the time elapsing between the application of an irritant to a sensory surface and the resulting movement will be considerably prolonged, the optic lobes (Setschenow's center) apparently generating impulses which, descending the cord, retard its reflex movement.

All movements taking place through the nervous system are of this reflex character, and may be divided into *excito-motor*, *sensori-motor*, and *ideo-motor.*

Classification of Reflex Movements. (Küss.) They may be divided into four groups, according to the route through which the centripetal and centrifugal impulses pass :—

1. Those normal reflex acts, *e.g.*, deglutition, coughing, sneezing, walking, etc.; pathologic reflex acts, *e.g.*, tetanus, vomiting, epilepsy, which take place both centripetally and centrifugally through spinal nerves.
2. Reflex acts which take place in a centripetal direction through a cerebro-spinal sensory nerve, and in a centrifugal direction through a sympathetic motor nerve, usually a vasomotor nerve, *e.g.*, the normal reflex acts, which give rise to most of the secretions, pallor, and blushing of the skin, certain movements of the iris, certain modifications in the beat of the heart; the pathologic, which, on account of the difficulty in explaining their production, are termed *metastatic*, *e. g.*, ophthalmia, coryza, orchitis, which depend on a reflex hyperemia; amaurosis, paralysis, paraplegia, etc., due to a reflex anemia.
3. Reflex movements, in which the centripetal impulse passes through a

sympathetic nerve, and the centrifugal through a cerebro-spinal nerve; most of these phenomena are pathological, *e.g.*, convulsions from intestinal irritation produced by the presence of worms, eclampsia, hysteria, etc.

4. Reflex actions, in which both the centripetal and centrifugal impulses pass through filaments of the sympathetic nervous system, *e.g.*, those obscure reflex actions which preside over the secretions of the intestinal fluids, which unite the phenomena of the generative organs, the dilatation of the pupils from intestinal irritation (worms), and many pathological phenomena.

Laws of Reflex Action. (Pflüger.)

1. *Law of Unilaterality.*—If a feeble irritation be applied to one or more sensory nerves, movement takes place usually on one side only, and that upon the same side as the irritation.
2. *Law of Symmetry.*—If the irritation becomes sufficiently intense, motor reaction is manifested, in addition, in corresponding muscles of the opposite side of the body.
3. *Law of Intensity.*—Reflex movements are usually more intense on the side of the irritation; at times the movements of the opposite side equal them in intensity, but they are usually less pronounced.
4. *Law of Radiation.*—If the excitation still continues to increase, it is propagated upward, and motor reaction takes place through centrifugal nerves coming from segments of the cord higher up.
5. *Law of Generalization.*—When the irritation becomes very intense, it is propagated in the medulla oblongata; motor reaction then becomes general, and it is propagated up and down the cord, so that all the muscles of the body are thrown into action, the medulla oblongata acting as a focus whence radiate all reflex movements.

Special Reflex Movements.

There are a number of reflex movements taking place through the spinal cord, a study of which enables the physician to determine the condition of its different segments. They may be divided into:—

1. Skin or superficial, and
2. Tendon or deep reflexes.

The skin reflexes are induced by irritation of the skin and mucous membranes, *e.g.*, pricking, pinching, scratching, etc. The following are the principal skin reflexes:—

1. *Plantar reflex*, consisting of contraction of the muscles of the foot, induced by stimulation of the sole of the foot; it involves the integrity of the reflex arc through the lower end of the cord.

2. *Gluteal reflex*, consisting of contraction of the glutei muscles when the skin over the buttock is stimulated; it takes place through the segments giving origin to the 4th and 5th lumbar nerves.
3. *Cremasteric reflex*, consisting of a contraction of the cremaster muscle, and a retraction of the testicle toward the abdominal ring, when the skin on the inner side of the thigh is stimulated; it depends upon the integrity of the segments giving origin to the 1st and 2d lumbar nerves.
4. *Abdominal reflex*, consisting of a contraction of the abdominal muscles when the skin upon the side of the abdomen is gently scratched; its production requires the integrity of the spinal segments from the 8th to the 12th.
5. *Epigastric reflex*, consisting of a slight muscular contraction in the neighborhood of the epigastrium when the skin between the 4th and 6th ribs is stimulated; it requires the integrity of the cord between the 4th and 7th dorsal nerves.
6. *Scapular reflex* consists of a contraction of the scapular muscles when the skin between the scapula is stimulated; it depends upon the integrity of the cord between the 5th cervical and 3d dorsal nerves.

The superficial reflexes, though variable, are generally present in health. They are increased or exaggerated when the gray matter of the cord is abnormally excited, as in tetanus, strychnia poisoning, and in disease of the lateral columns, leading to arrest of their normal functions. The tendon or deep reflexes are also of great value in diagnosing the condition of the spinal segments. They are induced by a sharp blow upon a tendon. The following are the principal forms:—

1. *Patella reflex* or *knee jerk*, consisting of a contraction of the extensor muscles of the thigh when the ligamentum patella is struck between the patella and tibia. This reflex is best observed when the legs are freely hanging over the edge of a table. The patella reflex is generally present in health, being absent in only two per cent.; it is greatly exaggerated in lateral sclerosis, in descending degeneration of the cord; it is absent in locomotor ataxia and in atrophic lesions of the anterior gray cornuæ.
2. *Ankle Jerk or Reflex.*—If the extensor muscles of the leg be placed upon the stretch and the tendo Achillis be sharply struck, a quick extension of the foot will take place.
3. *Ankle Clonus.*—This consists of a series of rhythmical reflex contractions of the gastrocnemius muscle, varying in frequency from six to ten per second. To elicit this reflex, pressure is made upon the sole so as to suddenly and energetically flex the foot at the ankle, thus putting the

tendo Achillis upon the stretch. The rhythmical movements thus produced continue so long as the tension is maintained. Ankle clonus is never present in health, but is very marked in lateral sclerosis of the cord.

The *toe reflex*, *peroneal reflex*, and *wrist reflex* are also present in sclerosis of the lateral columns and in the late rigidity of the hemiplegia.

Special Nerve Centers in Spinal Cord.—Throughout the spinal cord there are a number of special nerve centers, capable of being excited reflexly and producing complex coordinated movements. Though for the most part independent in action, they are subject to the controlling influences of the medulla and brain.

1. *Ciliospinal* center, situated in the cord between the lower cervical and 3d dorsal vertebra. It is connected with the dilatation of the pupil through fibers which emerge in this region and enter the cervical sympathetic. Stimulation of the cord in this locality causes dilatation of the pupil on the same side; destruction of the cord is followed by contraction of the pupil.
2. *Genitospinal* center, situated in the lower part of the cord. This is a complex center and comprises a series of subordinate centers for the control of the muscular movements involved in the acts of defecation, micturition, ejaculation of semen, the movements of the uterus during parturition, etc.
3. *Vasomotor* centers, giving origin to both vasoconstrictor and vasodilator fibers, which are distributed throughout the cord. Though acting reflexly they are under the dominating influence of the center in the medulla.
4. *Sweat* centers are also present in various parts of the cord.

2. As a Conductor.

The *lateral columns*, particularly the posterior portions, the "pyramidal tracts," and the columns of Türck, are the channels through which pass the voluntary motor impulses from the brain to the large multipolar nerve cells in the anterior cornuæ of gray matter, and through them become connected with the anterior roots which transmit the motor stimuli to the muscles.

The *anterior columns*, especially the portion surrounding the anterior cornuæ, the "anterior radicular zones," are composed of short longitudinal commissural fibers, which serve to connect together different segments of the spinal cord, a condition required for the coordination of muscular movements.

The *posterior columns* are composed of short and long commissural fibers which connect together different segments of the cord. They are insensible to direct irritation, but aid in the coordination of muscular movements in walking, standing, running, etc. Degeneration of the posterior columns gives rise to the lack of muscular coordination observed in locomotor ataxia.

The *gray matter*, and especially that portion immediately surrounding the central canal, transmits the sensory nerve fibers from the posterior roots up to the brain. Decussation of the sensory fibers takes place throughout the whole length of the gray matter.

The *multipolar cells* of the *anterior cornuæ* are connected with the generation and transmission of motor impulses outward; are centers for reflex movements; are the trophic centers for the motor nerves and muscular fibers to which they are distributed. The anterior roots give passage to the vasoconstrictor and vasodilator fibers which exert an influence upon the caliber of the blood-vessels. *Complete destruction* of the anterior horns is followed by a paralysis of motion, degeneration of the anterior roots, atrophy of muscles and bones, and an abolition of reflex movements.

Paralysis from Injuries of the Spinal Cord.

Seat of Lesion.—If it be in the *lower part* of the *sacral canal*, there is paralysis of the compressor urethræ, accelerator urinæ, and sphincter ani muscles; no paralysis of the muscles of the leg.

At the Upper Limit of the Sacral Region.—Paralysis of the muscles of the bladder, rectum, and anus; loss of sensation and motion in the muscles of the legs, except those supplied by the anterior crural and obturator, viz.: psoas iliacus, Sartorius, pectineus, adductor longus, magnus, and brevis, obturator, vastus externus and internus, etc.

At the Upper Limit of the Lumbar Region.—Sensation and motion paralyzed in both legs; lŏss of power over the rectum and bladder; paralysis of the muscular walls of the abdomen interfering with expiratory movements.

At the Lower Portion of the Cervical Region.—Paralysis of the legs, etc., as above; in addition, paralysis of all the intercostal muscles and consequent interference with respiratory movements; paralysis of muscles of the upper extremities, except those of the shoulders.

Above the Middle of the Cervical Region.—In addition to the preceding, difficulty of deglutition and vocalization, contraction of the pupils, paralysis of the diaphragm, scalene muscles, intercostals, and many of the accessory respiratory muscles; death resulting immediately from arrest of respiratory movements.

CRANIAL NERVES.

The Cranial Nerves come off from the base of the brain, pass through the foramina in the walls of the cranium, and are distributed to the skin, muscles, and organs of sense in the face and head.

According to the classification of Sœmmering, there are 12 pairs of nerves, enumerating them from before backward, as follows, viz.:—

1st Pair, or Olfactory.	7th Pair, or Facial, Portio dura.
2d Pair, or Optic.	8th Pair, or Auditory, Portio mollis.
3d Pair, or Motor oculi communis.	9th Pair, or Glosso-pharyngeal.
4th Pair, or Patheticus, Trochlearis.	10th Pair, or Pneumogastric.
5th Pair, or Trifacial, Trigeminus.	11th Pair, or Spinal accessory.
6th Pair, or Abducens.	12th Pair, or Hypoglossal.

The Cranial Nerves may also be classified physiologically, according to their function, into three groups:—

1. Nerves of special sense.
2. Nerves of motion.
3. Nerves of general sensibility.

1st Pair. Olfactory.

Apparent Origin.—From the inferior and internal portion of the anterior lobes of the cerebrum by three roots, viz.: an *external white root*, which passes across the fissure of Sylvius to the middle lobe of the cerebrum; an *internal white root*, from the most posterior part of the anterior lobe; a *gray root*, from the gray matter in the posterior and inner portion of the inferior surface of the anterior lobe.

Deep Origin.—Not satisfactorily determined.

Distribution.—The olfactory nerve, formed by the union of the three roots, passes forward along the under surface of the anterior lobe to the ethmoid bone, where it expands into the olfactory bulb. This bulb contains ganglionic cells, is grayish in color, and soft in consistence; it gives off from its under surface from 15 to 20 nerve filaments, the *true olfactory nerves*, which pass through the cribriform plate of the ethmoid bone, and are distributed to the Schneiderian mucous membrane. This membrane extends from the cribriform plate of the ethmoid bone downward, about one inch.

Properties.—The olfactory nerves give rise to neither motor nor sensory phenomena when stimulated. They carry simply the special impressions

of odorous substances. Destruction or injury of the olfactory bulbs is attended by a loss of the sense of smell.

Function.—Governs the sense of smell. Conducts the impressions which give rise to odorous sensations.

2d Pair. Optic.

Apparent Origin.—From the anterior portion of the optic commissure.

Deep Origin.—The origins and connections of the optic tract are very complex. The immediate origins are bands of fibers from the thalamus opticus and anterior corpora quadrigemina. The corpora geniculata are interposed ganglia. The ultimate roots are traced—

1. By a broad band of fibers—"the optic radiation of Gratiolet"—to the psycho-optic centers in the occipital lobes.
2. To the gyrus hippocampi and sphenoidal lobes.
3. Through the corpus callosum to the motor areas of the opposite cerebral hemispheres.
4. To the frontal region by "Meynert's Commissure."
5. To the spinal cord.
6. To the corpora geniculata, pulvinar, and anterior corpora geniculata by ganglionic roots.

Distribution.—The two roots unite to form a flattened band, the optic tract, which winds around the crus cerebri to decussate with the nerve of the opposite side, forming the *optic chiasm*. The decussation of fibers is not complete; some of the fibers of the left optic tract going to the outer half of the eye of the same side, and to the inner half of the eye of the opposite side; the same holds true for the right optic tract.

The *optic nerves proper* arise from the commissure, pass forward through the optic foramina, and are finally distributed in the *retinæ*.

Properties.—They are insensible to ordinary impressions, and convey only the *special impressions of light. Division* of one of the nerves is attended by complete blindness in the eye of the corresponding side.

Hemiopia and Hemianopsia.—Owing to the decussation of the fibers in the optic chiasm *division* of the *optic tract* produces *loss* of *sight* in the *outer half* of the eye of the same side, and in the *inner half* of the eye of the opposite side, the blind part being separated from the normal part by a vertical line. The term hemiopia is applied to the loss of function or paralysis of the one-half of the retina; hemianopsia is applied to the blindness in the field of vision. If, for example, the *right optic tract* be divided, there will be hemiopia in the outer half of the right eye and inner

half of left eye, thus causing *left lateral hemianopsia*, and as the two halves are affected which correspond in normal vision, it is spoken of as *homonymous hemianopsia.* Lesion of the anterior part of the *optic chiasm* causes blindness in the inner half of the two eyes.

Functions.—Governs the sense of sight. Receives and conveys to the brain the luminous impressions which give rise to the sensation of sight.

The reflex movements of the iris are called forth by the optic nerve. When an excess of light falls upon the retina the impression is carried back to the tubercula quadrigemina, where it is transformed into a motor impulse, which then passes outward through the motor oculi nerve to the contractile fibers of the iris and diminishes the size of the pupil. The absence of light is followed by a dilatation of the pupil.

3d Pair. Motor Oculi Communis.

Apparent Origin.—From the inner surface of the crura cerebri.

Deep Origin.—By three sets of filaments coming from the oculomotorius nucleus, which lies under the aqueduct of Sylvius; these three groups of filaments are destined for the innervation of the muscles of the eyeball, the sphincter pupillæ, and the ciliary muscle. By filaments coming from the lenticular nucleus, corpora quadrigemina, optic thalamus; these filaments converge to form a main trunk, which winds around the crus cerebri, in front of the pons Varolii.

Distribution.—The nerve then passes forward, and enters the orbit through the sphenoidal fissure, where it divides into a *superior branch* distributed to the *superior rectus* and *levator palpebræ* muscles; an *inferior* branch sending branches to the *internal* and *inferior recti*, and the *inferior oblique* muscles; filaments also pass into the *ciliary* or *ophthalmic* ganglion; from this ganglion the *ciliary nerves* arise which enter the eyeball, and are distributed to the *circular fibers of the iris* and the *ciliary muscle.* The 3d nerve also receives filaments from the cavernous plexus of the sympathetic and from the 5th nerve.

Properties.—*Irritation* of the root of the nerve produces contraction of the pupil, internal strabismus, muscular movements of eye, but no pain. *Division* of the nerve is followed by *ptosis* (falling of the upper eyelid), *external strabismus*, due to the unopposed action of the external rectus muscle; paralysis of the accommodation of the eye; *dilatation* of the pupil from paralysis of the circular fibers of the iris and ciliary muscle; and *inability* to *rotate* the eye, *slight protrusion*, and *double vision.* The

images are crossed; that of the paralyzed eye is a little above that of the sound, and its upper end inclined toward it.

Function.—Governs movements of the eyeball by animating all the muscles except the external rectus and superior oblique, the movements of the iris, elevates the upper lid, influences the accommodation of the eye for distances. Can be called into action by (1) voluntary stimuli, (2) by reflex action through irritation of the optic nerve.

4th Pair. Patheticus.

Apparent Origin.—From the superior peduncles of the cerebellum.

Deep Origin.—By fibers terminating in the corpora quadrigemina, lenticular nucleus, valve of Vieussens, and in the substance of the cerebellar peduncles; some filaments pass over the median line and decussate with fibers of the opposite side.

Distribution.—The nerve enters the orbital cavity through the sphenoidal fissure, and is distributed to the *superior oblique* muscle; in its course receives filaments from the ophthalmic branch of the 5th pair and the sympathetic.

Properties.—When the nerve is *irritated* muscular movements are produced in the superior oblique muscle, and the pupil of the eye is turned *downward* and *outward.* Division or paralysis lessens the movements and rotation of the globe downward and outward. The diplopia consequent upon this paralysis is homonymous, one image appearing above the other. The image of the paralyzed eye is below, its upper end inclined toward that of the sound eye.

Function.—Governs the movements of the eyeball produced by the action of the superior oblique muscles.

6th Pair.* Abducens. Motor Oculi Externus.

Apparent Origin.—From the groove between the anterior pyramidal body and the pons Varolii, where it arises by two roots.

Deep Origin.—From the gray matter of the medulla oblongata.

Distribution.—The nerve then passes into the orbit through the sphenoidal fissure, and is distributed to the *external rectus* muscle. Receives

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* The 6th nerve is considered in connection with the 3d and 4th nerves, since they together constitute the motor apparatus by which the ocular muscles are excited to action.

filaments from the cervical portion of the sympathetic, through the carotid plexus, and sphenopalatine ganglion.

Properties.—When *irritated*, the *external rectus muscle* is thrown into convulsive movements and the eyeball is turned outward. When *divided* or *paralyzed*, this muscle is paralyzed, motion of the eyeball outward past the median line is impossible, and the homonymous diplopia increases as the object is moved outward past this line. The images are upon the same plane and parallel. Internal strabismus results because of the unopposed action of the internal rectus.

Function.—To turn the eyeball outward.

5th Pair. Trifacial. Trigeminal.

Apparent Origin.—By two roots from the side of the pons Varolii.

Deep Origin.—The deep origin of the two roots is the upper part of the floor and anterior wall of the fourth ventricle, by three bundles of filaments, one of which anastomoses with the auditory nerve; another passes to the lateral tract of the medulla; while a third, grayish in color, goes to the restiform bodies, and may be traced to the point of the calamus scriptorius.

Filaments of origin have been traced to the "trigeminal sensory nucleus," located on a level with the point of exit of the nerve, and to the posterior gray horns of the cord, as low down as the middle of the neck.

Distribution.—The *large root* of the nerve passes obliquely upward and forward to the ganglion of Gasser, which receives filaments of communication from the carotid plexus of the sympathetic. It then divides into three branches:—

1. *Ophthalmic branch*, which receives communicating filaments from the sympathetic, and sends sensitive fibers to all the motor nerves of the eyeball. It is *distributed* to the ciliary ganglion, lacrimal gland, sac and caruncle, conjunctiva, integument of the upper eyelid, forehead, side of head and nose, anterior portion of the scalp, ciliary muscle, and iris.
2. *Superior maxillary branch*, sends branches to the spheno-palatine ganglion, integument of the temple and lower eyelid, side of forehead, nose, cheek, and upper lip, teeth of the upper jaw, and alveolar processes.
3. *Inferior maxillary branch*, which, after receiving in its course filaments from the *small root* and from the facial, is distributed to the submaxillary ganglion, the parotid and sublingual glands, external auditory meatus, mucous membrane of the mouth, anterior two-thirds of the tongue (lingual branch), gums, arches of the palate, teeth of the lower jaw

and integument of the lower part of the face, and *to the muscles of mastication*

The *small root* passes forward beneath the ganglion of Gasser, through the foramen ovale, and joins the *inferior maxillary* division of the large root, which then divides into an anterior and posterior branch, the former of which is distributed to the muscles of mastication, viz.: temporal, masseter, internal and external pterygoid muscles.

Properties.—It is the most acutely sensitive nerve in the body, and endows all the parts to which it is distributed with general sensibility.

Irritation of the *large root*, or any of its branches, will give rise to marked evidence of pain; the various forms of neuralgia of the head and face being occasioned by compression, disease, or exposure of some of its terminal branches.

Division of the large root within the cranium is followed at once by a complete abolition of all sensibility in the head and face, but is not attended by any loss of motion. The integument, mucous membranes, and the eye may be lacerated, cut, or bruised without the animal exhibiting any evidence of pain. At the same time the lacrimal secretion is diminished, the pupil becomes contracted, the eyeball is protruded, and the sensibility of the tongue is abolished.

The reflex movements of deglutition are also somewhat impaired; the impression of the food being unable to reach and excite the nerve center in the medulla oblongata.

Galvanization of the *small root* produces movements of the muscles of mastication; *section* of the root causes paralysis of these muscles, and the jaw is drawn to the opposite side by the action of the opposing muscles.

Influence of the Special Senses.—After division of the large root within the cranium, a disturbance in the nutrition of the special senses sooner or later manifests itself.

Sight.—In the course of twenty-four hours the *eye* becomes very vascular and inflamed, the cornea becomes opaque and ulcerates, the humors are discharged, and the eye is totally destroyed.

Smell.—The nasal mucous membrane swells up, becomes fungous, and is liable to bleed on the slightest irritation. The mucus is increased in amount, so as to obstruct the nasal passages; the sense of smell is finally abolished.

Hearing.—At times the hearing is impaired from disorders of nutrition in the middle ear and external auditory meatus.

Alteration in the nutrition of the special senses is not marked if the sec-

tion is made posterior to the ganglion of Gasser, and to the anastomosing filaments of the sympathetic which join the nerve at this point; but if the ganglion be divided, these effects are very noticeable, due to the section of the sympathetic filaments.

Function.—Gives sensibility to all parts of the head and face to which it is distributed; through the small root endows the masticatory muscles with motion; through fibers from the sympathetic governs the nutrition of the special senses.

7th Pair. Portio Dura. Facial Nerve.

Apparent Origin.—From the groove between the olivary and restiform bodies at the lateral portion of the medulla oblongata and below the margin of the pons Varolii.

Deep Origin.—From a nucleus of large cells in the floor of the 4th ventricle, below the nucleus of origin of the 6th pair, with which it is connected. Some filaments are traceable to the lenticular nucleus of the opposite side. Some of the fibers cross the median line and decussate. It is intimately associated with the nerve of Wrisberg at its origin.

Distribution.—From its origin the facial nerve passes into the internal auditory meatus, and then, in company with the nerve of Wrisberg, enters the aqueduct of Fallopius. The filaments of the nerve of Wrisberg are supplied with a ganglion, of a reddish color, having nerve cells. These filaments unite with those of the root of the facial to form a common trunk, which emerges at the stylomastoid foramen.

In the aqueduct the facial gives off the following branches, viz.:—

1. *Large petrosal nerve*, which passes forward to the *sphenopalatine*, or Meckel's ganglion, and through this to the levator palati and azygos uvulæ muscles, which receive motor influence from this source.
2. *Small petrosal nerve*, passing to the *otic* ganglion and thence to the *tensortympani* muscle, endowing it with motion.
3. *Tympanic branch*, giving motion to the stapedius muscle.
4. *Chorda tympani* nerve, which, after entering the posterior part of the tympanic cavity, passes forward between the malleus and incus bones, through the Glaserian fissure, and joins the lingual branch of the 5th nerve. It is then distributed to the mucous membrane of the anterior two-thirds of the tongue and the submaxillary glands.

After emerging from the stylomastoid foramen, the facial nerve sends branches to the muscles of the ear, the occipitofrontalis, the digastric, the palatoglossi, and palatopharyngei; after which it passes through the parotid

gland and divides into the *temporofacial* and *cervicofacial* branches, which are distributed to the superficial muscles of the face, viz.: occipitofrontalis, corrugator supercilii, orbicularis palpebrarum, levator labii superioris et alæque nasi, buccinator, levator anguli oris, orbicularis oris, zygomatici, depressor anguli oris, platysma myoides, etc.

Properties.—Undoubtedly a motor nerve at its origin, but in its course receives sensitive filaments from the 5th pair and the pneumogastric.

Irritation of the nerve, after its emergence from the stylomastoid foramen, produces convulsive movements in all the superficial muscles of the face. *Division* of the nerve at this point causes paralysis of these muscles on the side of the section, constituting *facial paralysis*, the phenomena of which are a relaxed and immobile condition of the same side of the face; the eyelids remain open, from paralysis of the orbicularis palpebrarum; the act of winking is abolished; the angle of the mouth droops, and saliva constantly drains away; the face is drawn over to the second side; the face becomes distorted upon talking or laughing; mastication is interfered with, the food accumulating between the gums and cheek, from paralysis of the buccinator muscle; fluids escape from the mouth in drinking; articulation is impaired, the labial sounds being imperfectly pronounced.

Properties of the Branches given off in the Aqueduct of Fallopius.—The *large petrosal*, when irritated, throws the levator palati and azygos uvulæ muscles into contraction. *Paralysis* of this nerve, from deep-seated lesions, produces a *deviation* of the uvula to the sound side, a *drooping* of the palate, and an inability to elevate it.

The *small petrosal* influences hearing by animating the tensor tympani muscle; when paralyzed, there occurs partial deafness and an increased sensibility to sonorous impressions.

The *tympanitic branch* animates the stapedius muscle and influences audition.

The *chorda tympani* influences the circulation and the secretion of saliva in the submaxillary glands, and governs the sense of taste in the anterior two-thirds of the tongue. *Galvanization* of the chorda tympani dilates the blood-vessels, increases the quantity and rapidity of the stream of blood, and increases the secretion of saliva. *Division* of the nerve is followed by contraction of the vessels, an arrestation of the secretion, and a diminution of the sense of taste, on the same side.

Function.—The facial is the nerve of expression, and coordinates the muscles employed to delineate the various emotions, influences the sense *of taste*, deglutition, movements of the uvula and soft palate, the tension of

the membrana tympani, and the secretions of the submaxillary and parotid glands. Indirectly influences smell, hearing, and vision.

8th Pair. Portio Mollis. Auditory Nerve.

Apparent Origin.—From the upper and lateral portion of the medulla oblongata, just below the margin of the pons Varolii.

Deep Origin.—By two roots from the floor of the 4th ventricle, each root consisting of a number of gray filaments, some of which decussate in the median line; the external root has a gangliform enlargement containing fusiform nerve cells.

Distribution.—The two roots wind around the restiform bodies and enter the internal auditory meatus, and divide into an anterior branch distributed to the cochlea, and a posterior branch distributed to the vestibule and semicircular canals.

Properties.—They are soft in consistence, grayish in color, consisting of axis cylinders with a medullary sheath only; they are not sensible to ordinary impressions, but convey the *impression of sound.*

Function.—Governs the sense of hearing. Receives and conducts to the brain the impression of sound, which gives rise to the sensations of hearing.

9th Pair. Glossopharyngeal.

Apparent Origin.—Partly from the medulla oblongata and the inferior peduncles of the cerebellum.

Deep Origin.—From the lower portion of the gray substance in the floor of the 4th ventricle.

This nerve has two ganglia; the *jugular ganglion* includes only a portion of the root filaments; the ganglion of Andersch includes all the fibers of the trunk.

Distribution.—The trunk of the nerve passes downward and forward, receiving near the ganglion of Andersch fibers from the facial and pneumogastric nerves. It divides into two large branches, one of which is distributed to the base of the tongue, the other to the pharynx. In its course it sends filaments to the otic ganglion; a tympanic branch which gives sensibility to the mucous membrane of the fenestra rotunda, fenestra ovalis, and Eustachian tube; lingual branches to the base of the tongue; palatal branches to the soft palate, uvula, and tonsils; pharyngeal branches to the mucous membrane of the pharynx.

Properties.—*Irritation* of the roots at their origin calls forth evidences of pain; it is, therefore, a sensory nerve, but its sensibility is not so acute

as that of the trifacial. *Irritation* of the trunk after its exit from the cranium produces contraction of the muscles of the palate and pharynx, due to the presence of anastomosing motor fibers.

Division of the nerve abolishes sensibility in the structures to which it is distributed and impairs the sense of taste in the posterior third of the tongue (see Sense of Taste).

Function.—Governs sensibility of pharynx, presides partly over the sense of taste, and controls reflex movements of deglutition and vomiting.

10th Pair. Pneumogastric. Par Vagum.

Apparent Origin.—From the lateral side of the medulla oblongata, just behind the olivary body.

Deep Origin.—In the gray nuclei in the lower half of the floor of the 4th ventricle and in the substance of the restiform body. Some filaments are traced along the restiform tract, toward the cerebellum, and others to the median line of the floor of the 4th ventricle, where many of them decussate.

This nerve has two ganglia, one in the jugular foramen, called the ganglion of the root, and another outside of the cranial cavity on the trunk, the ganglion of the trunk.

Distribution.—The filaments from the root unite to form a single trunk, which leaves the cavity of the cranium, through the jugular foramen, in company with the spinal accessory and glossopharyngeal. It soon receives an *anastomotic branch* from the *spinal accessory*, and afterward branches from the facial, the hypoglossal, and the anterior branches of the two upper cervical nerves.

As the nerve passes down the neck it sends off the following main branches:—

1. *Pharyngeal nerves*, which assist in forming the pharyngeal plexus, which is distributed to the mucous membrane and muscles of the pharynx.
2. *Superior laryngeal nerve*, which enters the larynx through the thyrohyoid membrane, and is distributed to the mucous membrane lining the interior of the larynx, and to the cricothyroid muscle and the inferior constrictor of the pharynx. The "*depressor nerve*," found in the rabbit, is formed by the union of two branches, one from the superior laryngeal, the other from the main trunk; it passes downward to be distributed to the heart.
3. *Inferior laryngeal*, which sends its ultimate branches to all the intrinsic muscles of the larynx except the cricothyroid, and to the inferior constrictor of the pharynx.

4. *Cardiac* branches given off from the nerve throughout its course, which unite with the sympathetic fibers to form the cardiac plexus, to be distributed to the heart.
5. *Pulmonary branches*, which form a plexus of nerves and are distributed to the bronchi and their ultimate terminations, the lobules and air cells.

From the right pneumogastric nerve branches are distributed to the mucous membrane and muscular coats of the stomach and intestines, to the liver, spleen, kidneys, and suprarenal capsules.

Properties.—At its origin the pneumogastric nerve is sensory, as shown by direct irritation or galvanization, though its sensibility is not very marked. In its course it exhibits motor properties, from anastomosis with motor nerves.

The *pharyngeal branches* assist in giving sensibility to the mucous membrane of the pharynx, and influence reflex phenomena of deglutition through motor fibers which they contain, derived from the spinal accessory.

The *superior laryngeal* nerve endows the upper portion of the larynx with sensibility; protects it from the entrance of foreign bodies; by conducting impressions to the medulla, excites the reflex movements of deglutition and respiration; through the motor filaments it contains produces contraction of the cricothyroid muscle.

Division of the "*depressor nerve*" and *galvanization* of the central end retard and even arrest the pulsations of the heart, and by depressing the vasomotor center diminish the pressure of blood in the large vessels, by causing dilatation of the intestinal vessels through the splanchnic nerves.

The *inferior laryngeal* contains, for the most part, motor fibers from the spinal accessory. When *irritated*, produces movement in the laryngeal muscles. When *divided*, is followed by paralysis of these muscles, except the cricothyroid, impairment of phonation, and an embarrassment of the respiratory movements of the larynx, and, finally, death from suffocation.

The *cardiac branches*, through filaments derived from the spinal accessory, exert a direct inhibitory action upon the heart. *Division* of the pneumogastrics in the neck increases the frequency of the heart's action. *Galvanization* of the peripheral ends diminishes the heart's pulsation, and, if sufficiently powerful, paralyzes it in diastole.

The *pulmonary branches* give sensibility to the bronchial mucous membrane and govern the movements of respiration. *Division* of both pneumogastrics in the neck diminishes the frequency of the respiratory movements, falling as low as four to six per minute; death usually occurs in from five to eight days. *Feeble galvanization* of the central ends of the

divided nerves accelerates respiration; *powerful galvanization* retards, and may even arrest, the respiratory movements.

The *gastric branches* give sensibility to the mucous coat, and through sympathetic filaments, which join the pneumogastrics high up in the neck, give motion to the muscular coat of the stomach. They influence the secretion of gastric juice, aid the process of digestion and absorption from the stomach.

The *hepatic branches*, probably through anastomosing sympathetic filaments, influence the secretion of bile and the glycogenic function of the liver; *division* of the pneumogastrics in the neck produces congestion of the liver, diminishes the density of the bile, and arrests the glycogenic function; *galvanization* of the central ends exaggerates the glycogenic function and makes the animal diabetic.

The *intestinal branches* give sensibility and motion to the small intestines, and when divided, purgatives generally fail to produce purgation.

Function.—A great sensitive nerve, which, through anastomotic filaments from motor sources, influences deglutition, the action of the heart, the circulatory and respiratory systems, voice, the secretions of the stomach, intestines, and various glandular organs.

11th Pair. Spinal Accessory.

Apparent Origin.—By two sets of filaments :—

1. A bulbar or medullary set, four or five in number, from the lateral or motor tract of the lower half of the medulla oblongata, below the origin of the pneumogastric.
2. A spinal set, from six to eight in number, from the lateral portion of the spinal cord, between the anterior and posterior roots of the upper four or five cervical nerves.

Deep Origin.—The *medullary portion* arises in a nucleus in the lower half of the floor of the 4th ventricle, common to the pneumogastric and glossopharyngeal nerves. The *spinal portion* has its origin in an elongated nucleus lying along the external surface of the anterior cornua of the spinal cord, extending down to the 5th cervical vertebra.

Distribution.—From this origin the fibers unite to form a main trunk, which enters the cranial cavity through the foramen magnum, where it is at times joined by fibers from the posterior roots of the two upper cervical nerves, and sends filaments to the ganglion of the root of the pneumogastric. After emerging from the cranial cavity through the jugular foramen, it sends a branch to the pneumogastric and receives others in return,

and also from the 2d, 3d, and 4th cervical nerves. It divides into two branches :—

1. An *internal* or *anastomotic* branch, made up of filaments coming principally from the medulla oblongata, and is distributed to the muscles of the pharynx through the pharyngeal nerves coming from the pneumogastric ; to all the muscles of the larynx, except the cricothyroid, through the *inferior laryngeal* nerve ; to the heart, by filaments which reach it through the pneumogastric nerve.
2. An *external branch*, which is distributed to the sternocleidomastoid and trapezius muscles ; these muscles also receiving filaments from the cervical nerves.

Properties.—At its origin it is a purely *motor* nerve, but in its course exhibits some sensibility from anastomosing fibers.

Destruction of the *medullary root*, by tearing it from its attachment by means of forceps, impairs the action of the muscles of deglutition and destroys the power of producing vocal sounds by paralysis of the laryngeal muscles, without, however, interfering with the respiratory movements of the larynx, these being controlled by other motor nerves. The normal rate of movement of the heart is also impaired by destruction of the medullary root.

Irritation of the external branch throws the trapezius and sternomastoid muscles into convulsive movements, though *section* of the nerve does not produce complete paralysis, as they are also supplied with motor influence from the cervical nerves. The sternomastoid and trapezius muscles perform movements antagonistic to those of respiration, fixing the head, neck, and upper part of the thorax, and delaying the expiratory movement during the acts of pushing, pulling, straining, etc., and in the production of a prolonged vocal sound, as in singing. When the *external* branch alone is divided, in animals, they experience shortness of breath during exercise, from a want of coordination of the muscles of the limbs and respiration ; and while they can make a vocal sound, it cannot be prolonged.

Function.—Governs phonation by its influence upon the vocal movements of the glottis ; influences the movements of deglutition, inhibits the action of the heart, and controls certain respiratory movements associated with sustained or prolonged muscular efforts and phonation.

12th Pair. Hypoglossal or Sublingual.

Apparent Origin.—By two groups of filaments from the medulla oblongata, in the grooves between the olivary body and the anterior pyramid.

Deep Origin.—From the hypoglossal nucleus situated deeply in the substance of the medulla, on a level with the lowest portion of the floor of the 4th ventricle; some decussating filaments have been traced to a higher encephalic center.

Distribution.—The trunk formed by a union of the root filament passes out of the cranial cavity through the anterior condyloid foramen, occasionally receiving a filament from the lateral and posterior portion of the medulla oblongata. After emerging from the cranium, it sends filaments to the sympathetic and pneumogastric; it anastomoses with the lingual branch of the 5th pair, and receives and sends filaments to the upper cervical nerves. The nerve is finally distributed to the sternohyoid, sternothyroid, omohyoid, thyrohyoid, styloglossi, hyoglossi, geniohyoid, geniohyoglossi, and the intrinsic muscles of the tongue.

Properties.—A purely *motor* nerve at its origin, but derives sensibility outside the cranial cavity from anastomosis with the cervical, pneumogastric, and 5th nerves.

Irritation of the nerve gives rise to convulsive movements of the tongue and slight evidences of sensibility.

Division of the nerve abolishes all movements of the tongue and interferes considerably with the act of deglutition.

When the hypoglossal nerve is involved in hemiplegia, the tip of the tongue is directed to the paralyzed side when the tongue is protruded, due to the unopposed action of the geniohyoglossus on the sound side.

Articulation is considerably impaired in paralysis of this nerve, great difficulty being experienced in the pronunciation of the consonantal sounds.

Mastication is performed with difficulty, from inability to retain the food between the teeth until it is completely triturated.

Function.—Governs all the movements of the tongue and influences the functions of mastication, deglutition, and articulate language.

MEDULLA OBLONGATA.

The Medulla Oblongata is the expanded portion of the upper part of the spinal cord. It is pyramidal in form and measures one and a half inches in length, three-quarters of an inch in breadth, half an inch in thickness, and is divided into two lateral halves by the anterior and posterior median fissures, which are continuous with those of the cord. Each half is again subdivided by minor grooves into four columns, viz.: *anterior*

pyramid, *lateral tract* and *olivary body*, *restiform body*, and *posterior pyramid*.

1. The *anterior pyramid* is composed partly of fibers continuous with those of the anterior column of the spinal cord, but mainly of fibers derived from the lateral tract of the opposite side by *decussation*. The united fibers then pass upward through the pons Varolii and crura cerebri, and for the most part terminate in the corpus striatum and cerebrum.

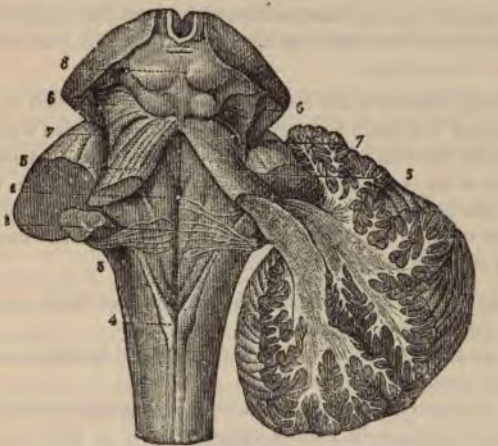

FIG. 18.—VIEW OF CEREBELLUM IN SECTION, AND OF 4TH VENTRICLE, WITH THE NEIGHBORING PARTS.—(*From Sappey.*)

1. Median groove 4th ventricle, ending below in the *calamus scriptorius*, with the longitudinal eminences formed by the fasciculi teretes, one on each side. 2. The same groove, at the place where the white streaks of the auditory nerve emerge from it to cross the floor of the ventricle. 3. Inferior peduncle of the cerebellum, formed by the restiform body. 4. Posterior pyramid; above this is the calamus scriptorius. 5. Superior peduncle of cerebellum, or *processus e cerebello ad testes*. 6, 6. Fillet to the side of the crura cerebri. 7, 7. Lateral grooves of the crura cerebri. 8. *Corpora quadrigemina*.—(*After Hirschfeld and Leveille.*)

2. The *lateral tract* is continuous with the lateral columns of the cord; its fibers in passing upward take three directions, viz.: an external bundle joins the restiform body, and passes into the cerebellum; an internal bundle decussates at the median line and joins the opposite anterior pyramid; a middle bundle ascends beneath the olivary body, behind the pons, to the cerebrum, as the *fasciculus teres*. The *olivary body* of each

side is an oval mass, situated between the anterior pyramid and restiform body; it is composed of white matter externally and gray matter internally, forming the *corpus dentatum*.

3. The *restiform body*, continuous with the posterior column of the cord, also receives fibers from the lateral column. As the restiform bodies pass upward they diverge and form a space, the 4th ventricle, the floor of which is formed by gray matter, and then turn backward and enter the cerebellum.
4. The *posterior pyramid* is a narrow, white cord bordering the posterior median fissure; it is continued upward, in connection with the *fasciculus teres*, to the cerebrum.

The Gray Matter of the medulla is continuous with that of the cord. It is arranged with much less regularity, becoming blended with the white matter of the different columns, with the exception of the anterior. By the separation of the posterior columns, the transverse commissure is exposed, forming part of the floor of the 4th ventricle; special collections of gray matter are found in the posterior portions of the medulla, connected with the roots of origin of different cranial nerves.

Properties and Functions.—The medulla is excitable anteriorly and sensitive posteriorly to direct irritation. It serves—

1. As a conductor of sensitive impressions upward from the cord, through the gray matter to the cerebrum.
2. As a conductor of voluntary impulses from the brain to the spinal cord and nerves, through its anterior pyramids.
3. As a conductor of coordinating impulses from the cerebellum, through the restiform bodies to the spinal cord.

As an Independent Reflex Center.—The medulla oblongata contains special collections of gray matter, which constitute independent nerve centers which preside over different functions, some of which are as follows, viz.:—

1. A center which controls the movements of *mastication*, through afferent and efferent nerves. (See page 82.)
2. A center reflecting impressions which influence the *secretion* of *saliva*. (See page 86.)
3. A *center for sucking, mastication, and deglutition*, whence are derived motor simuli exciting to action and coordinating the muscles of the palate, pharynx, and esophagus, necessary for the swallowing of the food. *The secretion of saliva* is also controlled by a center in the medulla.

NERVOUS CIRCLE OF DEGLUTITION.

2d and 3d Stages.

Excitor or Centripetal Nerves.	Palatal branch of the 5th pair. Pharyngeal branches of the glosso-pharyngeal. Superior laryngeal branches of the pneumogastric. Esophageal branches of the pneumogastric.
Motor or Centrifugal Nerves.	Pharyngeal branches of the pneumogastric, derived from the spinal accessory. Hypoglossal and branches of the cervical plexus. Inferior or recurrent laryngeal. Motor filaments of the 3d division of the 5th pair. Portio dura.

4. A center which coordinates the muscles concerned in the act of *vomiting.*
5. A *speech center*, coordinating the various muscles necessary for the accomplishment of articulation through the hypoglossal, facial nerves, and the 2d division of the 5th pair.
6. A center for the harmonization of muscles concerned in *expression*, reflecting its impulses through the facial nerve.
7. A *cardiac center*, which exerts (1) an *accelerating* influence over the heart's pulsations through accelerating nerve fibers emerging from the cervical portion of the cord, entering the inferior cervical ganglion, and thence passing to the heart; (2) an *inhibitory* or retarding influence upon the action of the heart, through fibers of the spinal accessory nerve running in the trunk of the pneumogastric. The cardio-inhibitory center is in a state of tonic excitement and continuously sending impulses to the heart which exert an inhibitory influence upon its action. It may be stimulated directly by anemia as well as venous hyperemia of the blood-vessels of the medulla and increased venosity of the blood. It is excited reflexly by the stimulation of the central end of the vagus, sciatic, and splanchnic nerves.
8. A *vasomotor center*, which, by alternately contracting and dilating the blood-vessels through nerves distributed in their walls, regulates the quantity of blood distributed to an organ or tissue, and thus influences nutrition, secretion, and calorification. The vasomotor center is situated in the medulla oblongata and pons Varolii, between the *corpora quadrigemina* and the *calamus scriptorius*. The vasomotor fibers having their origin in this center descend through the interior of the cord, emerge through the anterior roots of spinal nerves, enter the ganglia of the sympathetic, and thence pass to the walls of the blood-vessels, and maintain the *arterial tonus;* they may be divided into two classes, viz.: *vasodilators*, *e. g.*, chorda tympani, and *vasoconstrictors*, *e. g.*, sympathetic fibers.

Division of the cord at the lower border of the medulla is followed by a dilatation of the entire vascular system and a marked fall of the blood pressure. *Galvanic stimulation* of the divided surface of the cord is followed by a contraction of the blood vessels and a rise in the blood pressure.

The vasomotor center is stimulated directly by the condition of the blood in the medulla oblongata. When it is highly venous it becomes very active and the blood-vessels throughout the body are contracted and the blood current becomes swifter; sudden anemia of the medulla has a similar effect. This center may be increased in action, with attendant rise of blood pressure, by irritation of certain afferent nerve fibers. These are known as *pressor* fibers. On the other hand, its action may be depressed by other afferent fibers with attendant fall of blood pressure. These are known as *depressor* fibers.

9. A *diabetic center*, irritation of which causes an increase in the amount of urine secreted and the appearance of a considerable quantity of sugar.
10. *Respiratory center*, situated near the origin of the pneumogastric nerves, presides over the movements of respiration and its modifications, laughing, singing, sobbing, sneezing, etc. It may be excited *reflexly* by the presence of carbonic acid in the lungs irritating the terminal pneumogastric filaments; or *automatically*, according to the character of the blood circulating through it; an *excess* of carbonic acid or a diminution of oxygen increasing the number of respiratory movements; a reverse condition diminishing the respiratory movements.
11. A *spasm center*, stimulation of which gives rise to convulsive phenomena, such as coughing, sneezing, etc.
12. A *center for certain ocular functions*, governing the closure of the eyelids and dilatation of the pupil.
13. A *sweat center* is also localized in the medulla.

NERVOUS CIRCLE OF RESPIRATION

(*Entirely Reflex*).

Excitor or Centripetal Nerves.	Pulmonary branches of the pneumogastric. Superior laryngeal. Trifacial, or 5th pair. Nerves of general sensibility. Sympathetic nerve.
Motor or Centrifugal Nerves.	Phrenic, distributed to the diaphragm. Intercostals, distributed to the intercostal muscles. Facial nerve, or portio dura, to the facial muscles. External branch of spinal accessory, to the trapezius and sternocleidomastoid muscles.

PONS VAROLII.

The Pons Varolii unites together the cerebrum above, the cerebellum behind, and the medulla oblongata below. It consists of transverse and longitudinal fibers, amidst which are irregularly scattered collections of gray or vesicular nervous matter.

The *transverse fibers* unite the two lateral halves of the cerebellum.

The *longitudinal fibers* are continuous—

1. With the anterior pyramids of the medulla oblongata, which, interlacing with the deep layers of the transverse fibers, ascend to the crura cerebri, forming their superficial or fasciculated portions.
2. With fibers derived from the olivary fasciculus, some of which pass to the tubercula quadrigemina, while others, uniting with fibers from the lateral and posterior columns of the medulla, ascend in the deep or posterior portions of the crura cerebri.

Properties and Functions.—The superficial portion is *insensible* and *inexcitable* to direct irritation; the deeper portion appears to be *excitable*, consisting of descending motor fibers; the posterior portions are *sensible* but *inexcitable* to irritation.

Transmits motor impulses and sensory impressions from and to the cerebrum.

The *gray ganglionic* matter consists of centers which convert impressions into conscious sensations and originate motor impulses, these taking place independent of any intellectual process; they are the seat of instinctive reflex acts, the centers which assist in the coordination of the automatic movements of station and progression.

CRURA CEREBRI.

The Crura Cerebri are largely composed of the longitudinal fibers of the pons (anterior pyramids, fasciculi teretes); after emerging from the pons they increase in size, and become separated into two portions by a layer of dark gray matter, the *locus niger*.

The *superficial* portion, the *crusta*, composed of the anterior pyramids, constitutes the *motor tract*, which terminates, for the most part, in the *corpus striatum*, but to some extent, also, in the cerebrum; the *deep portion*, made up of the fasciculi teretes and posterior pyramids and accessory fibers

from the cerebellum, constitute the *sensory tract* (the *tegmentum*), which terminates in the *optic thalamus* and cerebrum.

Function.—The crura are conductors of motor impulses and sensory impressions; the gray matter, the *locus niger*, assists in the coordination of the complicated movements of the eyeball and iris, through the motor oculi communis nerve. They also assist in the harmonization of general muscular movements, section of one crus giving rise to peculiar movements of rotation and somersaults forward and backward.

CORPORA QUADRIGEMINA.

The Corpora Quadrigemina are four small, rounded eminences, two on each side of the median line, situated immediately behind the 3d ventricle, and beneath the posterior border of the corpus callosum.

The *anterior* tubercles are oblong from before backward, and larger than the *posterior*, which are hemispherical in shape; they are grayish in color, but consist of white matter externally and gray matter internally.

Both the anterior and posterior tubercles are connected with the optic thalami by commissural bands named the *anterior* and *posterior brachia*, respectively. They receive fibers from the olivary fasciculus and fibers from the cerebellum, which pass upward to enter the optic thalami.

The *corpora geniculata* are situated, one on the inner side and one on the outer side of each optic tract, behind and beneath the optic thalamus, and from their position are named the *corpora geniculata interna* and *externa;* they give origin to fibers of the optic nerve.

Functions.—The *Tubercula quadrigemina* are the physical centers of sight, translating the luminous impressions into visual sensations. Destruction of these tubercles is immediately followed by a loss of the sense of sight; moreover, their action in vision is crossed, owing to the decussation of the optic tracts, so that if the tubercle of the right side be destroyed by disease or extirpated, in a pigeon, the sight is *lost* in the eye of the opposite side, and the iris loses its mobility.

The tubercula quadrigemina as nerve centers preside over the reflex movements which cause a dilatation or contraction of the iris, irritation of the tubercles causing contraction, destruction causing dilatation. Removal of the tubercles on one side produces a temporary loss of power of the opposite side of the body, and a tendency to move around an axis is manifested, as after a section of one crus cerebri, which, however, may be due to giddiness and loss of sight.

They also assist in the coordination of the complex movements of the eye, and regulate the movements of the iris during the movements of accommodation for distance.

CORPORA STRIATA AND OPTIC THALAMI.

The Corpora Striata are two large ovoid collections of gray matter, situated at the base of the cerebrum, the larger portions of which are imbedded in the white matter, the smaller portions projecting into the anterior part of the lateral ventricle. Each striated body is divided, by a narrow band of white matter, into two portions, viz. :—

1. The *caudate nucleus*, the intraventricular portion, which is conical in shape, having its apex directed backward, as a narrow, tail-like process.
2. The *lenticular nucleus*, imbedded in the white matter, and for the most part external to the ventricle; on the outer side of the lenticular nucleus is found a narrow band of white matter, the *external capsule;* and between it and the convolutions of the island of Reil a thin band of gray matter, the *claustrum;* the corpora striata are grayish in color, and when divided present transverse striations, from the intermingling of white fibers and gray cells.

The Optic Thalami are two oblong masses situated in the ventricles posterior to the corpora striata, and resting upon the posterior portion of the crura cerebri. The internal surface projecting into the lateral ventricles is white, but the interior is grayish, from a commingling of both white fibers and gray cells. Separating the lenticular nucleus from the caudate nucleus and the optic thalamus is a band of white tissue, the *internal capsule*.

The *internal capsule* is a narrow, bent tract of white matter, and is, for the most part, an expansion of the *motor tract* of the crura cerebri. It consists of two segments, *an anterior*, situated between the caudate nucleus and the anterior surface of the lenticular nucleus, and a *posterior*, situated between the optic thalamus and the posterior surface of the lenticular nucleus. These two segments unite at an obtuse angle, which is directed toward the median line. Pathologic observation has shown that the nerve fibers of the direct and crossed pyramidal tracts can be traced upward through the anterior two-thirds of the posterior segment into the centrum ovale, where, for the most part, they are lost; a portion, however, remaining united, ascend higher and terminate in the paracentral lobule, the superior extremity of the ascending frontal and parietal convolutions. The *sensory tract* can be traced upward, through the posterior third, into

the cerebrum, where they probably terminate in the hippocampus major and unciate convolution.

Functions.—The *corpora striata* are the centers in which terminate some of the fibers of the superficial or *motor* tract of the crura cerebri; others pass upward through the *internal capsule*, to be distributed to the cerebrum. It might be inferred, from their anatomical relations, that they are motor centers. *Irritation* by a weak galvanic current produces muscular movements of the opposite side of the body; *destruction* of their substance by a hemorrhage, as in apoplexy, is followed by a paralysis of motion of the opposite side of the body, but there is no loss of sensation. When the hemorrhagic destruction involves the fibers of the anterior two-thirds of the posterior segment of the internal capsule, and thus separates them from their trophic centers in the cortical motor region, a descending degeneration is established, which involves the direct pyramidal tract of the same side and the crossed pyramidal tract of the opposite side.

Destruction of the posterior one-third of the posterior segment of the internal capsule is followed by a loss of sensation on the opposite side of the body and a loss of the senses of smell and vision on the same side (Charcot). The precise function of the corpora striata is unknown, but they are in some way connected with motion.

The *optic thalami* receives the fibers of the *tegmentum*, the posterior portion of the crura cerebri. They are insensible and inexcitable to direct irritation. Removal of one optic thalamus, or destruction of its substance by disease or hemorrhage, is followed by a loss of sensibility of the opposite side of the body, but there is no loss of motion; their precise function is also unknown, but in some way connected with *sensation*. In both cases their action is crossed.

CEREBELLUM.

The Cerebellum is situated in the inferior fossæ of the occipital bone, beneath the posterior lobes of the cerebrum. It attains its maximum weight, which is about five ozs., between the twenty-fifth and fortieth years, the proportion between the cerebellum and cerebrum being 1 to 8¾.

It is composed of *two lateral hemispheres* and a central elongated lobe, the *vermiform process;* the two hemispheres are connected with each other by the fibers of the *middle peduncle* forming the superficial portion of the pons Varolii. It is brought into connection with the *medulla oblongata* and *spinal cord* through the prolongation of the *restiform* bodies; with the cerebrum, by fibers passing upward beneath the corpora quadrigemina

and the optic thalami, and then forming part of the diverging cerebral fibers.

Structure.—It is composed of both white and gray matter, the former being internal, the latter external, and convoluted, for economy of space.

The *White matter* consists of a central stem, the interior of which is a dentated capsule of gray matter, the *corpus dentatum*. From the external surface of the stem of white matter processes are given off, forming the *laminæ*, which are covered with gray matter.

The *Gray matter* is convoluted and covers externally the laminated processes; a vertical section through the gray matter reveals the following structures :—

1. A delicate *connective tissue layer*, just beneath the pia mater, containing rounded corpuscles, and branching fibers passing toward the external surface.
2. *The cells of Purkinje*, forming a layer of large, nucleated, branched nerve cells sending off processes to the external layer.
3. *A granular layer* of small but numerous corpuscles.
4. *Nerve fiber layer*, formed by a portion of the white matter.

Properties and Functions.—Irritation of the cerebellum is not followed by any evidences either of pain or convulsive movements; it is, therefore, *insensible* and *inexcitable*.

Coordination of Movements.—Removal of the superficial portions of the cerebellum in pigeons produces *feebleness* and *want of harmony* in the muscular movements; as successive slices are removed, the movements become more irregular, and the pigeon becomes restless; when the last portions are removed, all power of *flying*, *walking*, *standing*, etc., is entirely gone, and the *equilibrium* cannot be maintained, the power of *coordinating* muscular movements being entirely gone. The same results have been obtained by operating on all classes of animals.

The following symptoms were noticed by Wagner, after removing the whole or a large part of the cerebellum :—

1. A tendency on the part of the animal to throw itself on one side, and to extend the legs as far as possible.
2. Torsion of the head on the neck.
3. Trembling of the muscles of the body, which was general.
4. Vomiting and occasionally liquid evacuations.

Forced Movements.—Division of *one crus cerebelli* causes the animal to fall on one side and roll rapidly on its longitudinal axis. According to Schiff, if the peduncle be divided from *behind*, the animal falls on the same

side as the injury; if the section be made in *front*, the animal turns to the opposite side.

Disease of the cerebellum partially corroborates the result of experiments; in many cases symptoms of unsteadiness of gait, from *a want of coordination*, have been noticed.

Comparative anatomy reveals a remarkable correspondence between the development of the cerebellum and the complexity of muscular actions. It attains a much greater development, relatively to the rest of the brain, in those animals whose movements are very complex and varied in character, such as the kangaroo, shark, and swallow.

The cerebellum may possibly exert some influence over the sexual function, but physiologic and pathologic facts are opposed to the idea of its being the seat of the sexual instinct. It appears to be simply a center for the coordination and equilibration of muscular movements.

CEREBRUM.

The Cerebrum is the largest portion of the encephalic mass, constituting about four-fifths of its weight; the average weight in the adult male is from 48 to 50 ounces, or about three pounds, while in the adult female it is about five ounces less. After the age of forty the weight of the cerebrum gradually diminishes at the rate of one ounce every ten years. In idiots the brain weight is often below the normal, at times not amounting to more than 20 ounces.

The Blood Supply to the cerebrum is unusually large, considering its comparative bulk, nearly *one-fifth* of the entire volume of blood being distributed to it by the carotid and vertebral arteries. These vessels anastomose so freely, and are so arranged within the cavity of the cranium, that an obstruction in one vessel will not interfere with the regular supply of blood to the parts to which its branches are distributed. A diminished amount, or complete cessation, of the supply of blood is at once followed by a suspension of its functional activity.

The cerebrum is connected with the pons Varolii and medulla oblongata through the crura cerebri, and with the cerebellum through the superior peduncles. It is divided into two lateral halves, or hemispheres, by the longitudinal fissure running from before backward in the median line; each hemisphere is composed of both *white* and *gray* matter, the former being internal, the latter external; it covers the surfaces of the hemisphere which are infolded, forming convolutions, for economy of space.

Fissures.

1. The *fissure of Sylvius* is one of the most important; it is the first to appear in the development of the fetal brain, being visible at about the third month; in the adult it is quite deep and well marked, running from the under surface of the brain upward, outward, and backward, and forms a boundary between the frontal and temporosphenoidal lobes.
2. The *fissure of Rolando* is second in importance, and runs from a point on the convexity near the median line transversely outward and downward toward the fissure of Sylvius, but does not enter it. It separates the frontal from the parietal lobe.
3. The *parietal fissure*, arising a short distance behind the fissure of Rolando, upon the convexity of the hemisphere, runs downward and backward to its posterior extremity.
4. The *parieto-occipital fissure*, separating the occipital from the parietal lobes. Beginning upon the outer surface of the cerebrum, it is continued on the mesial aspect downward and forward until it terminates in the calcarine fissure.
5. The *callosomarginal fissure* lying upon the mesial surface, where it runs parallel with the corpus callosum.

Secondary fissures of importance are found in different lobes of the cerebrum, separating the various convolutions. In the anterior lobe are found the *precentral*, *superior frontal*, and *inferior frontal* fissures; in the temporosphenoidal lobes are found the *first* and *second temporosphenoidal fissures*; in the occipital lobe, the *calcarine* and *hippocampal fissures*.

Convolutions. Frontal lobe.

The *ascending frontal convolution*, situated in front of the fissure of Rolando, runs downward and forward; it is continuous above with the anterior frontal, and below with the inferior frontal convolution.

The *superior frontal convolution* is bounded internally by the longitudinal fissure, and externally by the superior frontal fissure; it is connected with the superior end of the frontal convolution, and runs downward and forward to the anterior extremity of the frontal lobe, where it turns backward, and rests upon the orbital plate of the frontal bone.

The *middle frontal convolution*, the largest of the three, runs from behind forward, along the sides of the lobe, to its anterior part; it is bounded above by the superior and below by the inferior frontal fissures.

The *inferior frontal convolution* winds around the ascending branch of the fissure of Sylvius, in the anterior and inferior portion of the cerebrum.

Parietal Lobe.—The *ascending parietal convolution* is situated just

behind the fissure of Rolando, running downward and forward; above, it becomes continuous with the upper parietal convolution, and below, winds around to be united with the ascending frontal.

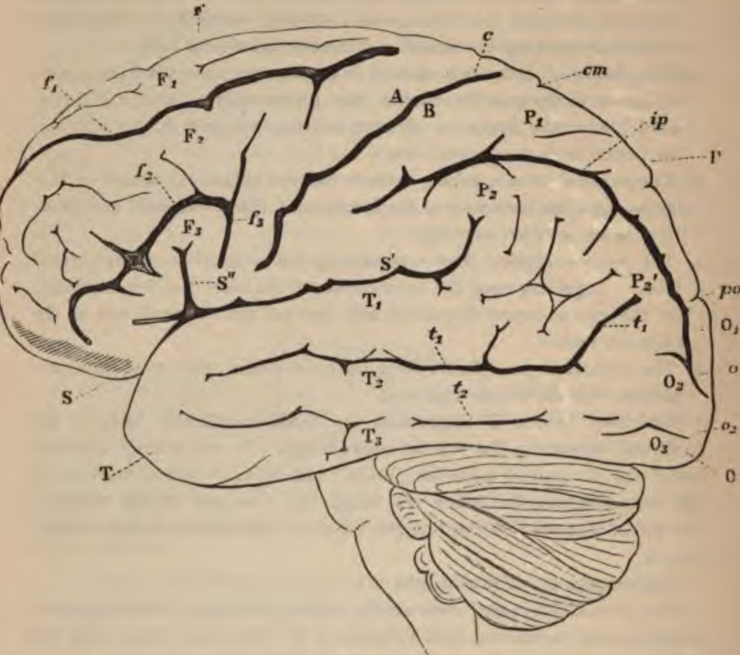

FIG. 19.—DIAGRAM SHOWING FISSURES AND CONVOLUTIONS OF THE LEFT SIDE OF THE HUMAN BRAIN.

F. Frontal. P. Parietal. O. Occipital. T. Temporo-sphenoidal lobe. S. Fissure of Sylvius. S'. Horizontal. S''. Ascending ramus of S. c. Sulcus centralis, or fissure of Rolando. A. Ascending frontal, and B. Ascending parietal, convolution. F_1. Superior, F_2. Middle, and F_3. Inferior frontal convolutions. f_1. Superior, f_2. Inferior, frontal fissures. f_3. Sulcus præcentralis. P. Superior parietal lobule. P_2. Inferior parietal lobule, consisting of P_2 Supramarginal gyrus, and P'_2. Angular gyrus. *i p.* Sulcus interparietalis. *c m.* Termination of callosomarginal fissure. O_1. First, O_2. Second, O_3. Third, occipital convolutions. *p o.* Parieto-occipital fissure. *o.* Transverse occipital fissure. o_2. Inferior longitudinal occipital fissure. T_1. First, T_2. Second, T_3. Temperosphenoidal, convolutions. t_1. First, t_2. Second, temporosphenoidal fissures.—(*Landois' Physiology.*)

The *upper parietal convolution* is situated between the parietal and longitudinal fissures.

The *supramarginal convolution* winds around the superior extremity of the fissure of Sylvius.

The *angular convolution*, a continuation of the preceding, follows the parietal fissure to its posterior extremity, and then makes a sharp angle downward and forward.

Temporosphenoidal Lobe.—Contains three well-marked convolutions, the *superior*, *middle*, and *inferior*, separated by well-defined fissures, and continuous posteriorly with the convolutions of the parietal lobe.

The Occipital Lobe lies behind the parieto-occipital fissure, and contains the *superior*, *middle*, and *inferior* convolutions, not well marked.

The *central lobe*, or *island of Reil*, situated at the bifurcation of the fissure of Sylvius, is a triangular-shaped cluster of six convolutions, the *gyri operti*, which are connected with those of the frontal, parietal, and temporosphenoidal lobes.

Upon the *inner* or *mesial* aspect of the hemisphere are found (Fig. 16)—

1. The *paracentral lobule*, lying in the region of the upper extremity of the fissure of Rolando; it contains the large giant cells of Betz. Injury to this convolution is followed by degeneration of the motor tract.
2. The *gyrus fornicatus*, lying below the callosomarginal fissure. Running parallel with the corpus callosum, it terminates at its posterior border in the hippocampal gyrus.
3. The *gyrus hippocampus* (H) is formed by the union of the preceding convolution with the occipitotemporal. It runs forward and terminates in a hooked extremity—*uncus*.
4. The *quadrate lobule* or *precuneus* lies between the upper extremity of the callosomarginal fissure and the parieto-occipital.
5. The *cuneus* lies posteriorly to the quadrate lobule. It is a wedge-shaped mass enclosed by the calcarine and parieto-occipital fissures.

Structure.—The *gray matter* of the cerebrum, about one-eighth of an inch thick, is composed of five layers of nerve cells:—

1. A superficial layer, containing a few small multipolar ganglion cells.
2. Small ganglion cells, pyramidal in shape.
3. A layer of large pyramidal ganglion cells with processes running off superiorly and laterally.
4. The granular formation containing nerve cells.
5. Spindle-shaped and branching nerve cells of a moderate size.

The *white matter* consists of three distinct sets of fibers:—

1. The *diverging* or *peduncular* fibers are mainly derived from the columns of the cord and medulla oblongata; passing upward through the crura

cerebri, they receive accessory fibers from the olivary fasciculus, corpora quadrigemina, and cerebellum. Some of the fibers terminate in the optic thalami and corpora striata, while others radiate into the anterior, middle, and posterior lobes of the cerebrum.

2. The *transverse commissural* fibers connect together the two hemispheres, through the corpus callosum and anterior and posterior commissures.
3. The *longitudinal commissural* fibers connect together different parts of the same hemisphere.

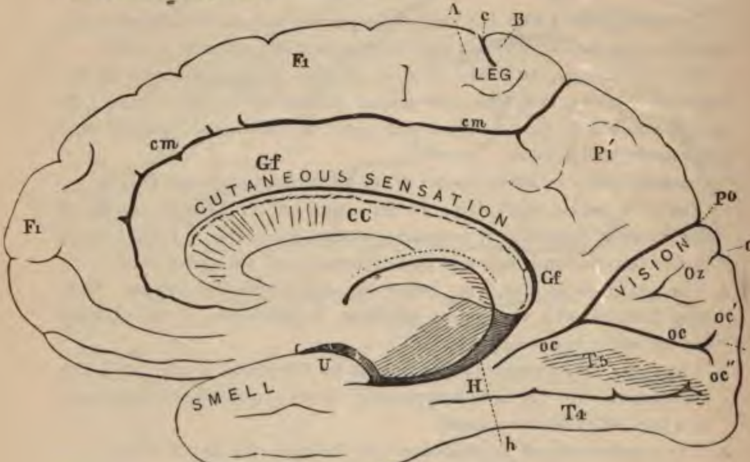

FIG. 20.—DIAGRAM SHOWING FISSURES AND CONVOLUTIONS ON MESIAL ASPECT OF THE RIGHT HEMISPHERE.

Median aspect of the right hemisphere. CC. Corpus callosum divided longitudinally. Gf. Gyrus fornicatus. H. Gyrus hippocampi. *h*. Sulcus hippocampi. U. Uncinate gyrus. *cm*. Calloso-marginal fissure. F. First frontal convolution. *c*. Terminal portion of fissure of Rolando. A. Ascending frontal, B. Ascending parietal, convolution and paracentral lobule. P_1'. Precuneus or quadrate lobule. Oz. Cuneus. Po. Parieto-occipital fissure. o_1. Transverse occipital fissure. *oc*. Calcarine fissure. *oc'*. Superior, *oc''*. Inferior, ramus of the same. D. Gyrus descendens. T_4. Gyrus occipitotemporalis lateralis (lobulus fusiformis). T_5. Gyrus occipitotemporalis medialis (lobulus lingualis).

Functions.—The cerebral hemispheres are the centers of the nervous system through which are manifested all the phenomena of the mind; they are the centers in which impressions are registered, and reproduced subsequently as ideas; they are the seat of intelligence, reason, and will.

However important a center the cerebrum may be for the exhibition of this highest form of nervous action, it is not directly essential for the con-

tinuance of life, for it does not exert any control over those automatic reflex acts, such as respiration, circulation, etc., which regulate the functions of organic life.

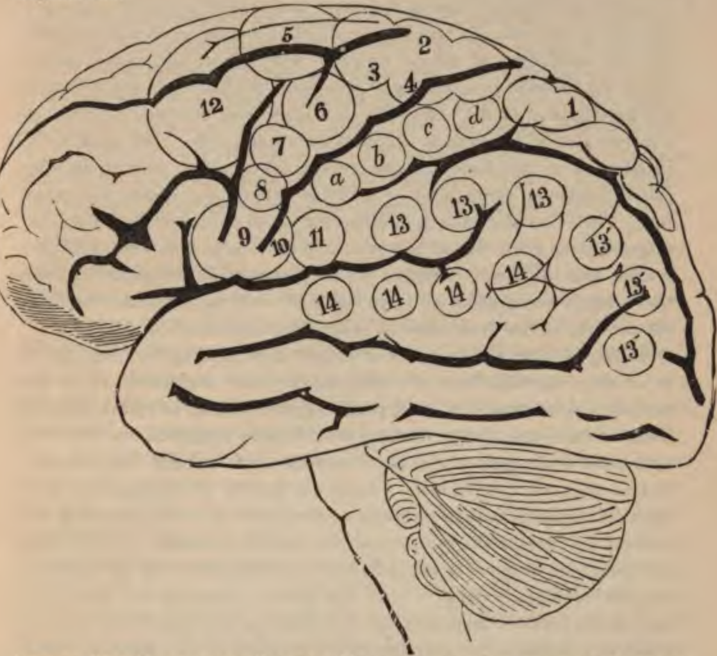

FIG. 21.—SIDE VIEW OF THE BRAIN OF MAN, WITH THE AREAS OF THE CEREBRAL CONVOLUTIONS ACCORDING TO FERRIER.

The figures are constructed by marking on the brain of man, in their respective situations, the areas of the brain of the monkey as determined by experiment, and the description of the effects of stimulating the various areas refers to the brain of the monkey.

1. Advance of the opposite hind limb, as in walking. 2, 3, 4. Complex movements of the opposite leg and arm, and of the trunk, as in swimming. *a, b, c, d.* Individual and combined movements of the fingers and wrist of the opposite hand. Prehensile movements. 5. Extension forward of the opposite arm and hand. 6. Supination and flexion of the opposite forearm. 7. Retraction and elevation of the opposite angle of the mouth, by means of the zygomatic muscles. 8. Elevation of the ala nasi and upper lip, with depression of the lower lip on the opposite side. 9, 10. Opening of the mouth, with (9) protrusion and (10) retraction of the tongue; region of aphasia, bilateral action. 11. Retraction of the opposite angle of the mouth, the head turned slightly to one side. 12. The eyes open widely, the pupils dilate, and the head and eyes turn toward the opposite side. 13, 13'. The eyes move toward the opposite side with an upward (13) or downward (13') deviation. The pupils are generally contracted. 14. Pricking of the opposite ear, the head and eyes turn to the opposite side, and the pupils dilate largely.

From the study of comparative anatomy, pathology, vivisection, etc., evidence has been obtained which throws some light upon the physiology of the cerebral hemispheres.

1. *Comparative anatomy* shows that there is a general connection between the size of the brain, its texture, the depth and number of convolutions, and the exhibition of mental power. Throughout the entire animal series, the increase in intelligence goes hand in hand with an increase in the development of the brain. In man there is an enormous increase in size over that of the highest animals, the anthropoids. The most cultivated races of men have the greatest cranial capacity; that of the educated European being about 116 cubic inches, that of the Australian being about 60 cubic inches, a difference of 56 cubic inches. Men distinguished for great mental power usually have large and well-developed brains; that of Cuvier weighed 64 ozs.; that of Abercrombie 63 ozs.; the average being about 48 to 50 ozs.; not only the size, but, above all, the texture, of the brain must be taken into consideration.
2. *Pathology.*—Any severe injury or disease disorganizing the hemispheres is at once attended by a disturbance, or entire suspension, of mental activity. A blow on the head, producing concussion, or undue pressure from cerebral hemorrhage, destroys consciousness; physical and chemical alterations in the gray matter have been shown to coexist with insanity, loss of memory, speech, etc. Congenital defects of organization from imperfect development are usually accompanied by a corresponding deficiency of intellectual power and the higher instincts. Under these circumstances no great advance in mental development can be possible, and the intelligence remains at a low grade. In congenital idiocy not only is the brain of small size, but it is wanting in proper chemical composition, *phosphorus*, a characteristic ingredient of the nervous tissue, being largely diminished in amount.
3. *Experimentation* upon the lower animals by removing the cerebral hemispheres is attended by results similar to those observed in disease and injury. Removal of the cerebrum in pigeons produces complete abolition of intelligence, and destroys the capability of performing spontaneous movements. The pigeon remains in a condition of profound stupor, which is not accompanied, however, by a loss of sensation, or of the power of producing reflex or instinctive movements. The pigeon can be temporarily aroused by pinching the feet, loud noises, light placed before the eyes, etc., but soon relapses into a state of quietude, being unable to remember impressions and connect them with any train of ideas, the faculties of memory, reason, and judgment being completely abolished.

CEREBRAL LOCALIZATION OF FUNCTION.

From experiments made upon animals, and the results of clinical and post-mortem observations upon men, it has been shown that the phenomena of organic and psychical life are presided over by anatomically localized centers in the brain. A knowledge of the position of these centers becomes of the highest importance in localizing the seat of lesions, thrombi, hemorrhages, new growths, etc., which show themselves in paralysis, epilepsies, etc. It has not been possible to thus localize all functions, and to many parts of the brain no special use can be assigned. The following are the centers most definitely mapped out and that are of paramount importance :—

Motor Centers.—These are in the cortical gray matter, and are arranged along either side of the fissure of Rolando. This area is known as the *motor area* or *motor zone*, stimulation of which is followed by convulsive movements of the muscles of the opposite side of the body, while destruction of the gray matter of this area is followed by permanent paralysis of the muscles of the opposite side. From experiments made upon monkeys Ferrier has mapped out a number of motor centers which he has transferred to corresponding localities on the human brain (see Fig. 17). The descriptive test of the figure renders his results intelligible. Pathological studies have largely confirmed his deductions. In a general way it may be said that the upper third of the ascending frontal and parietal convolutions about this fissure preside over the movements of the leg of the opposite side of the body; the middle third controls the movements of the arm; the upper part of the inferior third is the facial area. The lowest part of the inferior third governs the motility of the lips and tongue, and this space, with the posterior extremity of the third frontal convolution, constitutes the *speech center*.

The experiments of Horsley and Schäfer have enabled them to furnish a new diagrammatic representation of the motor area and to more accurately define the special areas upon the lateral and mesial aspects of the brain of the monkey. The boundaries of the general and special areas as determined by these observers will be readily understood by an examination of Figs. 22 and 23.

For diagnostic purposes the motor areas for the face and limbs have been subdivided as follows :—

1. The *face area* may be divided into an upper part comprising about one-third, and a lower part comprising the remaining two-thirds. In the upper part are centers governing the movements of the *muscles of the*

opposite angle of the mouth and of the *lower face*. The anterior portion of the lower two-thirds controls the movements of the vocal cords and may be regarded as a laryngeal center; the posterior portion governs the opening and shutting of the mouth and the protrusion and retraction of the tongue.

2. The *upper limb area* may be subdivided as follows: The upper part controls the movements of the shoulder; posterior and below this point are centers for the elbow; below and anteriorly, centers for the wrist and finger movements, while lowest and posteriorly centers governing the thumb.
3. The *leg area* may be subdivided as follows: The anterior part, both on the mesial and lateral surfaces, contains centers governing the hip and

FIG. 22.—DIAGRAM OF THE MOTOR AREAS ON THE OUTER SURFACE OF A MONKEY'S BRAIN.—(*Horsley and Schäfer.*)

thigh movements; in the posterior part are centers for the movements of the leg and toes. The center for the big toe has been located in the paracentral lobule.

4. The *trunk area*, situated largely on the mesial surface, contains anteriorly centers governing the rotation and arching of the spine, while posteriorly are found centers governing movements of the tail and pelvis.
5. The *head area*, or *area for visual direction*, contains centers excitation of which causes "opening of the eyes, dilatation of the pupils, and turning of the head to the opposite side, with conjugate deviation of the eyes to that side."

The centers of origin of the nerves for the ocular muscles lie in the gray matter of the aqueduct of Sylvius. Destruction of the gray matter at these

points is followed by paralysis of the muscles of the opposite side of the body, and morbid growths, hemorrhages, or thrombi of the vessels of the part result in abnormal stimulation or interference of the functions corresponding to the nature and extent of the lesion. Cerebral or Jacksonian epilepsy is a result of local cortical disease.

Center for Speech.—Pathological investigations have demonstrated that the left 3d frontal convolution is of essential importance for speech. Adjoining this convolution are the centers controlling the motility of the lips, tongue, etc. In the majority of the cases the speech centers are on the left side of the brain, though in exceptional cases they are on the right side, especially in left-handed people. In deaf-mutes this convolution is very imperfectly developed, while in monkeys it is quite rudimentary.

FIG. 23.—DIAGRAM OF THE MOTOR AREAS ON THE MARGINAL CONVOLUTION OF A MONKEY'S BRAIN.—(*Horsley and Schäfer.*)

Lesions of the 3d frontal convolution on the left side, if the patient be right-handed, produce the various forms of *aphasia* or the partial or complete loss of the power of articulate speech.

Aphasia is of many degrees and kinds. In *ataxic* aphasia the patient is unable to communicate his thoughts by words, there being an inability to execute the movements of the mouth, etc., necessary for speech. In *agraphic* aphasia there is an inability to execute the movements necessary for writing, though the mental processes are retained. In the ataxic form the lesion is in the 3d frontal convolution, and in the agraphic form it is in the arm center.

In *amnesic aphasia* there is a loss of the memory of words, the purest

examples of which consist of the affections known as *word deafness* and *word blindness.* In word deafness the patient cannot understand vocal speech, though he is capable of hearing other sounds. This condition is associated with lesion of the first temporal convolution. In *word blindness* the patient cannot name a letter or a word when printed or written, though he can see all other objects. This condition is associated with impairment of the visual centers.

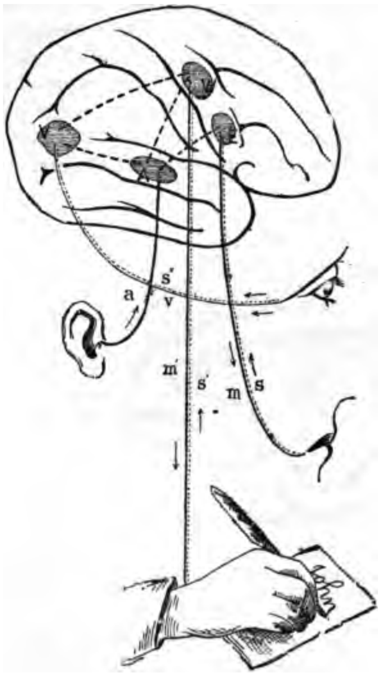

FIG. 24.

Fig. 24 will illustrate the conditions in the various forms of aphasia. Impressions are constantly passing from eye and ear to the visual and auditory centers and there registered. Commissural fibers connect these centers with the arm and speech centers, which in turn are connected by efferent fibers with the muscles of the hand and vocal apparatus. Muscular movements of the eyes, hand, and mouth are also registered by means of the afferent fibers, s, s′, s″.

Sensory Centers.—These are the centers in which the sensory impressions are coordinated, and in which they probably become parts of our consciousness. The most important are:—

The visual center, located in the occipital lobe and especially in the cuneus. Unilateral destruction of this area results in *hemianopsia*, or blindness of the corresponding halves of the two retinæ. Destruction of both occipital lobes in man results in total blindness. Stimulation or irritation of the visual center causes *photopsia*, or hallucinations of sight, in corresponding halves of the retinæ. There have been instances of injury of

these parts when sensations of color were abolished with preservation of those of space and light, thus showing a special localization of the color center. Late experiments show that the centers of the two hemispheres are united, as ocular fatigue of a nonused eye was proportional to the fatigue of the exercised one.

The auditory centers are located in the temporosphenoidal lobes. Word deafness is associated with softening of these parts, and their complete removal results in deafness.

The gustatory and olfactory centers are located in the uncinate gyrus, on the inner side of the temporosphenoidal lobes. There does not seem to be any differentiation, up to this time, of these two centers.

The center for tactile impressions was located by Ferrier in the hippocampal region. Horsley and Schäfer found that destructive lesions of the gyrus fornicatus was followed by hemianesthesia of the opposite side of the body, which was more or less marked and persistent. These observers conclude that the limbic lobe "is largely, if not exclusively, concerned in the appreciation of sensations painful and tactile."

The *superior* and *middle frontal convolutions* appear to be the seat of the reason, intelligence, and will. Destruction of these parts is followed by proportional hebetude, without any impairment of sensation or motion.

SYMPATHETIC NERVOUS SYSTEM.

The Sympathetic Nervous System consists of a chain of ganglia connected together by longitudinal nerve filaments, situated on each side of the spinal column, running from above downward. The two ganglionic cords are connected together in the interior of the cranium by the ganglion of Ribes, on the anterior communicating artery, and terminate in the ganglion impar, situated at the top of the coccyx.

The chain of ganglia is divided into groups, and named according to the location in which they are found, viz.: *cranial*, four in number; *cervical*, three; *thoracic*, twelve; *lumbar*, five; *sacral*, five; *coccygeal*, one. Each ganglion consists of a collection of *vesicular nervous* matter, bundles of nonmedullated nerve fibers, imbedded in a capsule of connective tissue. The ganglia are reinforced by motor and sensory fibers from the cerebrospinal nervous system.

The Ganglia have distinct nerve fibers from which branches are distributed to the glands, arteries, muscles, and to the cerebral and spinal

nerves; many pass, also, to the visceral ganglia, *e. g.*, cardiac, semilunar, pelvic, etc.

Cephalic Ganglia.

1. The *ophthalmic* or *ciliary* ganglion is situated in the orbital cavity posterior to the eyeball; it is of small size and of a reddish-gray color; receives filaments of communication from the motor oculi, ophthalmic branch of the 5th pair, and the carotid plexus. Its filaments of distribution are the ciliary nerves, which consist of—
   - *a*. *Motor* fibers for the circular fibers of the iris and ciliary muscle.
   - *b*. *Sensory* fibers for the cornea, iris, and associated parts.
   - *c*. *Vasomotor* fibers for the blood-vessels of the choroid, iris, and retina.
   - *d*. Motor fibers for the dilator fibers of the iris.
2. The *sphenopalatine*, or Meckel's ganglion, triangular in shape, is situated in the spheno-maxillary fossa; receives filaments from the facial (Vidian nerve), and the superior maxillary branch of the fifth nerve. Its filaments of distribution pass to the gums, the soft palate, levator palati, and azygos uvulæ muscle.
3. The *otic*, or Arnold's ganglion, is of small size, oval in shape, and situated beneath the foramen ovale; receives a motor filament from the facial, and sensory filaments from the glossopharyngeal and 5th nerve; sends filaments to the mucous membrane of the tympanic cavity and to the tensor tympani muscle.
4. The *submaxillary* ganglion, situated in the submaxillary gland, receives filaments from the chorda tympani, sensory filaments from the lingual branch of the 5th nerve, and filaments from the sympathetic. The chorda tympani nerve supplies *vasodilator* and *secretory* fibers to the submaxillary and sublingual glands. The 5th nerve endows the glands with sensibility, while the sympathetic supplies secretory or tropic fibers.

Cervical Ganglia.

The *superior cervical* ganglion is fusiform in shape, of a grayish-red color, and situate opposite the second and third cervical vertebræ; it sends branches to form the carotid and cavernous plexuses which follow the course of the carotid arteries to their distribution; also sends branches to join the glossopharyngeal and pneumogastric, to form the pharygeal plexus.

The *middle cervical* ganglion, the smallest of the three, is occasionally wanting; it is situated opposite the 5th cervical vertebra; sends branches to the superior and inferior cervical ganglion and to the thyroid artery.

The *inferior cervical* ganglion, irregular in form, is situated opposite the last cervical vertebra; it is frequently fused with the first thoracic ganglion.

The *superior*, *middle*, and *inferior cardiac nerves*, arising from these cervical ganglia, pass downward and forward to form the deep and superficial cardiac plexuses located at the bifurcation of the trachea, from which branches are distributed to the heart, coronary arteries, etc.

The Thoracic Ganglia are usually twelve in number, placed against the heads of the ribs behind the pleura; they are small in size and gray in color; they communicate with the cerebrospinal nerves by two filaments, one of which is white, the other gray.

The *great splanchnic nerve* is formed by the union of branches from the 6th, 7th, 8th, and 9th ganglia; it passes through the diaphragm to the semilunar ganglion.

The *lesser splanchnic nerve* is formed by the union of filaments from the 10th and 11th ganglia, and is distributed to the celiac plexus.

The *renal splanchnic nerve* arises from the last thoracic ganglion and terminates in the renal plexus.

The *semilunar ganglia*, the largest of the sympathetic, are situated by the side of the celiac axis; they send radiating branches to form the *solar plexus;* from the various plexuses, nerves follow the gastric, splenic, hepatic, renal, etc., arteries, into the different abdominal viscera.

The Lumbar Ganglia, four in number, are placed upon the bodies of the vertebra; they give off branches which unite to form the aortic lumbar plexus and the hypogastric plexus, and follow the blood-vessels to their terminations.

The Sacral and Coccygeal Ganglia send filaments of distribution to all the blood-vessels of the pelvic viscera.

Properties and Functions.—The sympathetic nerve possesses both sensibility and the power of exciting motion, but these properties are much less decided than in the cerebrospinal system. Irritation of the ganglia does not produce any evidence of pain until some time has elapsed. If caustic soda be applied to the semilunar ganglia, or a galvanic current be passed through the splanchnic nerve, no instantaneous effect is noticed, as in the case of the cerebrospinal nerves; but in the course of a few seconds a slow, progressive contraction of the muscular coat of the intestines is established, which continues for some time after the irritation is removed. *Division* of the sympathetic nerve in the neck is followed by a vascular congestion of the parts above the section on the corresponding side, attended by an increase in the temperature; not only is there an increase in the

amount of blood, but the rapidity of the blood current is very much hastened and the blood in the veins becomes of a brighter color. *Galvanization* of the upper end of the divided nerve causes all of the preceding phenomena to disappear; the congestion decreases, the temperature falls, and the venous blood becomes dark again.

The sympathetic exerts a similar influence upon the circulation of the limbs and the glandular organs; *destruction* of the 1st thoracic ganglion and division of the nerves forming the lumbar and sacral plexuses is followed by a dilatation of the vessels, an increased rapidity of the circulation, and an elevation of temperature in the anterior and posterior limbs; galvanization of the peripheral ends of these nerves causes all of these phenomena to disappear. Division of the splanchnic nerve causes a dilatation of the blood-vessels of the intestine.

These phenomena of the sympathetic nerve system are dependent upon the presence of vasomotor nerves, which, under normal circumstances, exert a tonic influence upon the blood-vessels. These nerves, derived from the cerebrospinal system, the medulla oblongata, leave the spinal cord by the *rami communicantes*, enter the sympathetic ganglia, and finally terminate in the muscular wall of the blood-vessels.

Sleep is a periodical condition of the nervous system, in which there is a partial or complete cessation of the activities of the higher nerve centers. The *cause* of sleep is a diminution in the quantity of blood, occasioned by a contraction of the smaller arteries under the influence of the vasomotor nerves.

During the waking state the brain undergoes a physiological waste, as a result of the exercise of its functions; after a certain length of time its activities become enfeebled, and a period of repose ensues, during which a regeneration of its substance takes place.

When the brain becomes enfeebled there is a diminished molecular activity and an accumulation of waste products; under these circumstances it ceases to dominate the medulla oblongata and the spinal cord. These centers then act more vigorously and diminish the caliber of the cerebral blood-vessels through the action of the vasomotor nerves, producing a condition of physiologic anemia and sleep; during this state waste products are removed, force is stored up, nutrition is restored, and waking finally occurs.

THE SENSE OF TOUCH.

The Sense of Touch is a modification of general sensibility, and located in the skin, which is especially adapted for this purpose, on account of the number of nerves and papillary elevations it possesses. The structures of the skin and the modes of termination of the sensory nerves have already been considered.

The Tactile Sensibility varies in acuteness in different portions of the body, being most marked in those regions in which the tactile corpuscles are most abundant, *e. g.*, the palmar surface of the 3d phalanges of the fingers and thumb.

The *relative sensibility* of different portions of the body has been ascertained by means of a pair of compasses, the points of which are guarded by cork, and then determining how closely they could be brought together, and yet be felt at two different points. The following are some of the measurements:—

Point of tongue,	½ of a line.
Palmar surface of third phalanx,	1 line.
Red surface of lips,	2 lines.
Palmar surface of metacarpus,	3 "
Tip of the nose,	3 "
Part of lips covered by skin,	4 "
Palm of hand,	5 "
Lower part of forehead,	10 "
Back of hand,	14 "
Dorsum of foot,	18 "
Middle of the thigh,	30 "

The sense of touch communicates to the mind the idea of *resistance* only, and the varying degrees of resistance offered to the sensory nerves enable us to estimate, with the aid of the muscular sense, the qualities of *hardness* and *softness* of external objects. The idea of *space* or *extension* is obtained when the sensory surface or the external object changes its place in regard to the other; the *character* of the surface, its *roughness* or *smoothness*, is estimated by the impressions made upon the tactile papillæ.

Appreciation of Temperature.—The general surface of the body is more or less sensitive to differences of temperature, though this sensation is separate from that of touch; whether there are nerves especially adapted for the conduction of this sensation has not been fully determined. Under pathologic conditions, however, the sense of touch may be abolished, while the appreciation of changes in temperature may remain normal.

The cutaneous surface varies in its sensibility to temperature in different parts of the body, and depends, to some extent, upon the thickness of the skin, exposure, habit, etc.; the inner surface of the elbow is more sensitive to changes in temperature than the outer portion of the arm; the left hand is more sensitive than the right; the mucous membrane less so than the skin.

Excessive heat or cold has the same effect upon the sensibility; the temperatures most readily appreciated are those between 50° F. and 115° F.

The sensations of *pain* and *tickling* appear to be conducted to the brain, also, by nerves different from those of touch; in abnormal conditions the appreciation of pain may be entirely lost, while touch remains unimpaired.

THE SENSE OF TASTE.

The Sense of Taste is localized mainly in the mucous membrane covering the superior surface of the tongue.

The Tongue is situated in the floor of the mouth; its base is directed backward and connected with the hyoid bone, by numerous muscles with the epiglottis and soft palate; its apex is directed forward against the posterior surface of the teeth.

The *substance* of the tongue is made up of intrinsic muscular fibèrs, the *linguales;* it is attached to surrounding parts, and its various movements performed by the extrinsic muscles, *e. g.*, styloglossus, geniohyoglossus, etc.

The *mucous membrane* covering the tongue is continuous with that lining the commencement of the alimentary canal, and is furnished with vascular and nervous papillæ.

The *papillæ* are analogous in their structure to those of the skin, and are distributed over the dorsum of the tongue, giving it its characteristic roughness.

There are three principal varieties:—

1. The *filiform papillæ* are most numerous, and cover the anterior two-thirds of the tongue; they are conical or filiform in shape, often prolonged into filamentous tufts, of a whitish color, and covered by horny epithelium.
2. The *fungiform papillæ* are found chiefly at the tip and sides of the tongue; they are larger than the preceding, and may be recognized by their deep red color.
3. The *circumvallate papillæ* are rounded eminences, from eight to ten in

number, situated at the base of the tongue, where they form a V-shaped figure. They are quite large, and consist of a central projection of mucous membrane, surrounded by a wall, or circumvallation, from which they derive their name.

The Taste Beakers, supposed to be the true organs of taste, are flask-like bodies, ovoid in form, about $\frac{1}{300}$th of an inch in length, situated in the epithelial covering of the mucous membrane, on the circumvallate papillæ. They consist of a number of fusiform, narrow cells, and curved so as to form the walls of this flask-like body; in the interior are elongated cells, with large, clear nuclei, the *taste cells*.

Nerves of Taste.—The *chorda tympani* nerve, a branch of the facial, after leaving the cavity of the tympanum, joins the 3d division of the 5th nerve between the two pterygoid muscles, and then passes forward in the lingual branches, to be distributed to the mucous membrane of the anterior two-thirds of the tongue. Division or disease of this nerve is followed by a *loss of taste* in the part to which it is distributed.

The *glossopharyngeal* enters the tongue at the posterior border of the hyoglossus muscle, and is distributed to the mucous membrane of the base and sides of the tongue, fauces, etc.

The *lingual branch of the trifacial* nerve endows the tongue with general sensibility; the *hypoglossal* endows it with motion.

The *nerves of taste* in the superficial layer of the mucous membrane form a fine plexus, from which branches pass to the epithelium and penetrate it; others enter the taste beakers, and are directly connected with the taste cells.

The *seat* of the sense of taste has been shown by experiment to be the whole of the mucous membrane over the dorsum of the tongue, soft palate, fauces, and upper part of the pharynx.

The Sense of Taste enables us to distinguish the savor of substances introduced into the mouth, which is different from tactile sensibility. The sapid quality of substances appreciated by the tongue are designated as bitter, sweet, alkaline, sour, salt, etc.

The Essential Conditions for the production of the impressions of taste are—

1. A state of solubility of the food.
2. A free secretion of the saliva, and
3. Active movements on the part of the tongue, exciting pressure against the roof of the mouth, gums, etc., thus aiding the solution of various articles and their osmosis into the lingual papillæ. Sapid substances,

when in a state of solution, pass into the interior of the taste beakers, and come into contact, through the medium of the taste cells, with the terminal filaments of the gustatory nerves.

THE SENSE OF SMELL.

The Sense of Smell is located in the mucous membrane lining the upper part of the nasal cavity, in which the olfactory nerves are distributed.

The Nasal Fossæ are two cavities, irregular in shape, separated by the vomer, the perpendicular plate of the ethmoid bone, and the triangular cartilage. They open anteriorly and posteriorly by the anterior and posterior nares, the latter communicating with the pharynx. They are lined by mucous membrane, of which the only portion capable of receiving odorous impressions is the part lining the upper one-third of the fossæ.

The Olfactory Nerves, arising by three roots from the posterior and inferior surface of the anterior lobes, pass forward to the cribriform plate of the ethmoid bone, where they each expand into an oblong body, the *olfactory bulb.* From its under surface from 15 to 20 filaments pass downward through the foramina, to be distributed to the olfactory mucous membrane, where they terminate in long, delicate, spindle-shaped cells, the *olfactory cells,* situated between the ordinary epithelial cells.

The olfactory bulbs are the centers in which odorous impressions are perceived as sensations, destruction of these bulbs being attended by an abolition of the sense of smell.

In animals which possess an acute sense of smell there is a corresponding increase in the development of the olfactory bulbs.

The Essential Conditions for the sense of smell are—

1. A special nerve center capable of receiving impressions and transforming them into odorous sensations.
2. Emanations from bodies which are in a gaseous or vaporous condition.
3. The odorous emanations must be drawn freely through the nasal fossæ; if the odor be very faint, a peculiar inspiratory movement is made, by which the air is forcibly brought into contact with the olfactory filaments.

The secretions of the nasal fossæ probably dissolve the odorous particles.

Various substances, as ammonia, horseradish, etc., excite the sensibility of the mucous membrane, which must be distinguished from the perception of true odors.

THE SENSE OF SIGHT.

The Eyeball.—The eyeball, or organ of vision, is situated at the fore part of the orbital cavity and supported by a cushion of fat; it is protected from injury by the bony walls of the cavity, the lids and lashes, and is so situated as to permit of an extensive range of vision. The eyeball is loosely held in position by a fibrous membrane, the *capsule of Tenon*, which is attached on the one hand to the eyeball itself and on the other to the walls of the cavity. Thus suspended, the eyeball is capable of being moved in any direction by the contraction of the muscles attached to it.

Structure.—The eyeball is spheroidal in shape and measures about $\frac{9}{10}$ths of an inch in its anteroposterior diameter, and a little less in its transverse diameter. When viewed in profile it is seen to consist of the segments of two spheres, of which the posterior is the larger, occupying $\frac{5}{6}$ths, and the anterior the smaller, occupying $\frac{1}{6}$th of the ball.

The eye is made up of several membranes concentrically arranged, within which are enclosed the refracting media essential to vision. These membranes, enumerated from without inward, are—

1. The sclerotic and cornea.
2. The choroid and iris.
3. The retina; the refracting media are the aqueous humor, the crystalline lens, and vitreous humor.

The Sclerotic and Cornea.—The sclerotic is the opaque fibrous membrane covering the posterior $\frac{5}{6}$ths of the ball. It is composed of connective tissue arranged in layers, which run both transversely and longitudinally; it is pierced posteriorly by the optic nerve about $\frac{1}{10}$th of an inch internal to the optic axis. The sclerotic by its density gives form to the eye and protects the delicate structures within it, and serves for the attachment of the muscles by which the ball is moved.

The cornea is a transparent nonvascular membrane covering the anterior $\frac{1}{6}$th of the eyeball. It is nearly circular in shape and is continuous at the circumference with the sclerotic, from which it cannot be separated. The substance of the cornea is made up of thin layers of delicate, transparent fibrils of connective tissue more or less united together; between these layers are found a number of intercommunicating lymph spaces lined by endothelium, which are in connection with lymphatics. Leucocytes or lymph corpuscles are often found in these spaces. The anterior surface of the cornea is covered by several layers of nucleated epithelium, which rest upon a structureless membrane known as the *anterior elastic lamina*. The

posterior surface is covered by a similar membrane, the membrane of Descemet, which becomes continuous at its periphery with the iris; it is also covered by a layer of epithelial cells. At the junction of the cornea and sclerotic is found a circular groove, the *canal of Schlemm.*

The Choroid, the Iris, the Ciliary Muscle, and Ciliary Processes together constitute the second or middle coat of the eyeball.

The choroid is a dark-brown membrane which extends forward nearly to the cornea, where it terminates in a series of folds, the *ciliary processes.* In its structure the choroid is highly vascular, consisting of both arteries and veins. Externally it is connected with the sclerotic by connective tissue; internally it is lined by a layer of hexagonal pigment cells which, though usually classed as belonging to the choroid, is now known to belong, embryologically and physiologically, to the retina. From without inward may be distinguished the following layers:—

1. The lamina supra choroidea.
2. The elastic layer of Sattler, consisting of two endothelial layers.
3. The chorio-capillaris, choroid proper, or membrane of Ruysch, a thick, elastic network of arterioles and capillaries lying within the outer layer of veins and arteries called the vena vorticosæ.
4. The lamina vitrea, or internal limiting membrane.

The choroid with its contained blood-vessels bears an important relation to the nutrition of the eye; it provides for the blood supply, for drainage from the body of the eye, and presents an uniform and high temperature to the retina.

The *iris* is the circular variously-colored membrane placed in the anterior portion of the eye just behind the cornea. It is perforated a little to the nasal side of the center by a circular opening, the *pupil.* The outer or circumferential border is connected with the cornea, ciliary muscle, and ciliary processes; the free inner edge forms the boundary of the pupil, the size of which is constantly changing. The framework of the iris is composed of connective-tissue blood-vessels, muscular fibers, and pigmented connective-tissue corpuscles. The anterior surface is covered with a layer of epithelial cells continuous with those covering the posterior surface of the cornea; the posterior surface is lined by a limiting membrane bearing pigment epithelial cells continuous with those of the choroid. The various colors which the iris assumes in different individuals depend upon the quantity and disposition of the pigmentary granules.

The muscular fibers of the iris, which are of the nonstriated variety, are arranged in two sets,—the sphincter and dilator.

The *sphincter pupillæ* is a circular flat band of muscular fibers surround-

ing the pupil close to its posterior surface; by its contraction and relaxation, the pupil is diminished or increased in size. The *dilator pupillæ* consists of a thin layer of fibers arranged in a radiate manner; at the margin of the pupil they blend with those of the sphincter muscle, while at the outer border they arch to form a circular muscular layer.

The *ciliary muscle* is a gray circular band consisting of unstriped muscular fibers about $\frac{1}{10}$th of an inch long running from before backward. It is attached anteriorly to the inner surface of the sclerotic and cornea, and posteriorly to the choroid coat opposite the ciliary processes. At the anterior border of the radiating fibers and internally are found bundles of

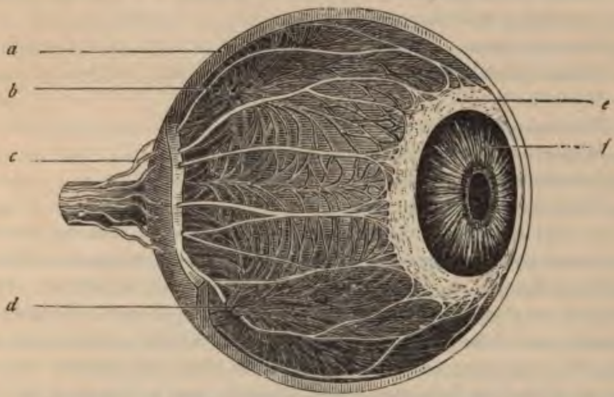

FIG. 25.—SCLEROTIC COAT REMOVED TO SHOW CHOROID, CILIARY MUSCLES, AND NERVES.
a. Sclerotic coat. *b*. Veins of the choroid. *c*. Ciliary nerves. *d*. Veins of the choroid. *e*. Ciliary muscle. *f*. Iris.—(*From Holden's Anatomy*.)

circular muscular fibers, constituting the *annular muscle* of Müller. The ciliary muscle thus consists of two sets of fibers, a radiating and circular, both of which are concerned in effecting a change in the convexity of the lens in the accommodation of the eye to near vision.

The **Retina** forms the internal coat of the eye. In the fresh state it is a delicate, transparent membrane of a pink color, but after death soon becomes opaque; it extends forward almost to the ciliary processes, where it terminates in an indented border, the *ora serrata*. In the posterior part of the retina at a point corresponding to the axis of vision is a yellow spot, the *macula lutea*, which is somewhat oval in shape and tinged with yellow

pigment. It presents in its center a depression, the *fovea centralis*, corresponding to a decrease in thickness of the retina; about $\frac{1}{10}$th of an inch to the inner side of the macula is the point of entrance of the optic nerve. The *arteria centralis retinæ* pierces the optic nerve near the sclerotic, runs forward in its substance, and is distributed in the retina as far forward as the ciliary processes.

The retina is remarkably complex, consisting of ten distinct layers, from within outward, supported by connective tissue. These are as follows, viz.:—

1. Membrana limitans interna.
2. Fibers of optic nerve.
3. Layers of ganglionic corpuscles.
4. Molecular layer.
5. Internal granular layer.
6. Molecular layer.
7. External granular layer.
8. Membrana limitans externa.
9. Jacobson's membrane, or layer of rods and cones.
10. The layer of pigment cells.

The most important of these, however, is the layer of rods and cones in the external portion of the retina. The rods are straight, elongated cylinders extending through the entire thickness of Jacobson's membrane. They consist of an external portion, which is clear, homogeneous, and highly refracting, and of an internal portion, which is slightly granular and less refractive; the outer end of each rod is in direct contact with the pigmentary epithelium lining the choroid, while the inner end, tapering to a fine thread, pierces the external limiting membrane and passes into the external granular layer. The cones consist also of two portions, the inner of which is somewhat thicker than the rod and rests upon the limiting membrane; the outer portion tapers to a fine point, which is known as the cone-style. The cones, as a rule, are somewhat shorter than the rods. The proportion of rods to cones varies in different parts of the retina, though there are on the average about fourteen rods to one cone. In the macula lutea, where vision is most acute, the rods are almost entirely absent, cones alone being present. All the retinal elements at this point are changed. The nerve fiber layer is absent, the axis cylinders radiating in such a manner as to leave the spot free from their covering. The remaining layers are all thinned and the stroma reduced to a minimum. The optic nerve after passing forward from the brain penetrates in succession the sclerotic, choroid, and retina; the nerve fibers then spread out over the anterior

surface of the retina and become connected with the large ganglionic cells, the 3d layer of the retina.

The number of optic nerve fibers in the retina is estimated to be about 800,000, and for each fiber there are about seven cones, one hundred rods, and seven pigment cells. The points of the rods and cones are directed toward the choroid, or away from the entering light, and dip into the pigmentary layer. They, with the pigment layer, are the elements intermediating the change of the ethereal vibrations into nerve force; out of these nerve vibrations the brain fashions the sensations of light, form, and color.

The *vitreous humor*, which supports the retina, is the largest of the refracting media; it is globular in form and constitutes about $\frac{4}{5}$ths of the ball; it is hollowed out anteriorly for the reception of the crystalline lens. The outer surface of the vitreous is covered by a delicate, transparent membrane, termed the *hyaloid membrane*, which serves to maintain its globular form.

The *aqueous humor* found in the anterior chamber of the eye is a clear alkaline fluid, having a specific gravity of 1.003–1.009. It is secreted most probably by the blood-vessels of the iris and ciliary processes. It passes from the interior of the eye, through the canal of Schlemm and the meshes at the base of the iris, into the anterior circular vein.

The *crystalline lens*, enclosed within its capsule, is a transparent biconvex body, situated just behind the iris and resting in the depression in the anterior part of the vitreous. The two convexities are not quite alike, the curvature of the posterior surface being slightly greater than that of the anterior. The lens measures about $\frac{1}{3}$d of an inch in the transverse diameter and $\frac{1}{5}$th of an inch in the anteroposterior diameter.

The *suspensory ligament*, by which the lens is held in position, is a firm, transparent membrane, united to the ciliary processes. A short distance beyond its origin it splits into two layers, the anterior of which is inserted into the capsule of the lens and blends with it; the posterior, passing inward behind the lens, becomes united to its capsule. The anterior layer presents a series of foldings, *Zone of Zinn*, which are inserted into the intervals of the folds of the ciliary processes. The triangular space between the two layers is the canal of Petit.

Blood-vessels and Nerves.—The structures composing the eyeball are supplied with blood by the long and short ciliary arteries, branches of the ophthalmic; they pierce the sclerotic at various points and are ultimately distributed to all tissues within the ball.

The nerve supply comes largely from the ophthalmic or ciliary ganglion. This is a small body, situated in the posterior part of the orbit; it receives

motor fibers from a branch of the motoroculi, or 3d nerve; a sensory branch from the ophthalmic division of 5th nerve, and fibers from the cavernous plexus of the sympathetic. From the anterior border of the ganglion proceed the ciliary nerves, which, entering the eyeball, endow its structures with motion and sensation.

The Eyeball a Living Camera Obscura.—The eyeball may be compared in a general way to a camera obscura. The anatomical arrangement of its structures reveals many points of similarity. The sclerotic and choroid may be compared with the walls of the chamber; the combined refractive media, cornea, aqueous humor, lens, and vitreous humor, to the lens for

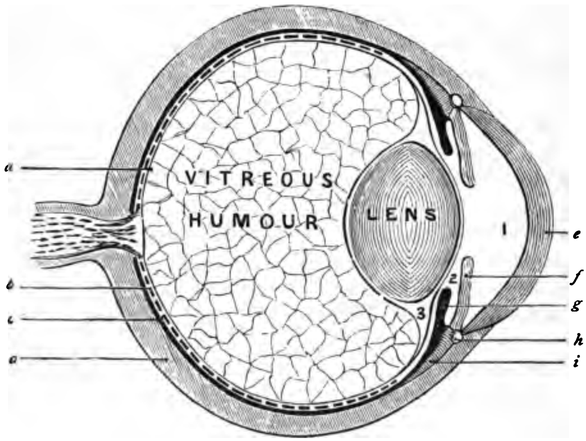

FIG. 26.—DIAGRAM OF A VERTICAL SECTION OF THE EYE.
1. Anterior chamber filled with aqueous humor. 2. Posterior chamber. 3. Canal of Petit.
a. Hyaloid membrane. *b*. Retina (dotted line). *c*. Choroid coat (black line). *d*. Sclerotic coat. *e*. Cornea. *f*. Iris. *g*. Ciliary processes. *h*. Canal of Schlemm or Fontana. *i*. Ciliary muscle.—(*From Holden's Anatomy.*)

focusing the rays of light; the retina, to the sensitive plate receiving the image formed at the focal point; the iris, to the diaphragm, which by cutting off the marginal rays prevents spherical aberration and at the same time regulates the amount of light entering the eye; the ciliary muscle, to the adjusting screw, by which distinct images are thrown upon the retina in spite of varying distances of the object from which the light rays emanate. The structures just enumerated are those essential for normal vision.

The relationship of the various structures composing the eyeball is shown *in Fig. 26.*

The Dioptric, or Refracting apparatus, by which the rays of light entering the eye are so manipulated as to produce an image on the retina, consists of the cornea, aqueous humor, crystalline lens, and vitreous humor. A ray of light in passing through each of these media will undergo refraction at their surfaces and ultimately be brought to a focus at the retina. Inasmuch as the two surfaces of the cornea are parallel and its refractive power practically the same as the aqueous humor, the media may be reduced to three, viz.:—

1. Cornea and aqueous humor.
2. The lens.
3. The vitreous humor.

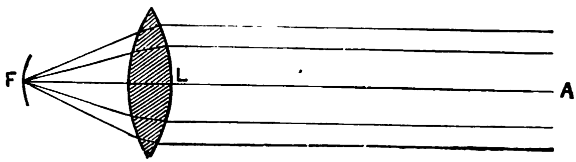

FIG. 27.—DIAGRAM SHOWING THE COURSE OF PARALLEL RAYS OF LIGHT FROM A, IN THEIR PASSAGE THROUGH A BICONVEX LENS, L, IN WHICH THEY ARE SO REFRACTED AS TO BEND TOWARD AND COME IN A FOCUS AT A POINT, F.—(*From Yeo's Text-Book of Physiology.*)

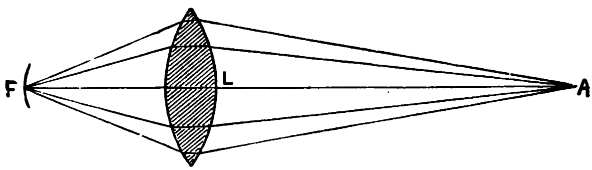

FIG. 28.—DIAGRAM SHOWING THE COURSE OF DIVERGING RAYS WHICH ARE BENT TO A POINT FURTHER FROM THE LENS THAN THE PARALLEL RAYS IN PRECEDING FIGURE.—(*From Yeo's Text-Book of Physiology.*)

The refracting surfaces may also be reduced to three, viz.:—

1. Anterior surface of the cornea.
2. Anterior surface of lens.
3. Posterior surface of lens.

The refraction effected by the cornea is very great, owing to the passage of the light from the air into a comparatively dense medium, and is sufficient of itself to bring parallel rays of light to a focus about ten millimeters behind the retina. This would be the condition in an eye in which the lens was congenitally absent. Perfect vision requires, however, that the convergence

of the light shall be great enough that the image may fall upon the retina. This is accomplished by the crystalline lens, a body denser than the cornea and possessing a higher refractive power. The manner in which a biconvex lens focuses both parallel and divergent rays is shown in Figs. 27 and 28.

The function of the crystalline lens, therefore, is to focus the rays of light with the formation of an image on the retina.

The Retinal Image corresponds in all respects to the object from which the light proceeds. The existence of this image can be demonstrated by removing from the eye of a recently killed animal a circular portion of the sclerotic and choroid posteriorly and then placing at the proper distance in front of the cornea a lighted candle; an inverted image of the candle will be seen upon the retina. The size of the retinal image depends upon the visual angle, which in turn depends upon the size of the object and its distance from the eye. At a distance of 15.2596 meters the image of an object one meter high would be one millimeter, or a thousand times smaller than the object.

Accommodation.—By accommodation is understood the power which the eye possesses of adjusting itself to vision at different distances. In a normal or emmetropic eye parallel rays of light are brought to a focus on the retina; but divergent rays, that is, rays coming from a near luminous point, will be brought to a focus behind the retina, provided the refractive media remain the same; as a result, vision would be indistinct, from the formation of diffusion circles. It is impossible to see distinctly, therefore, a near and distant object at the same time. We must alternately direct the vision from one to the other. A normal eye does not require adjusting for parallel rays; but for divergent rays a change in the eye is necessitated; this is termed accommodation. In the accommodation for near vision the lens becomes more convex, particularly on its anterior surface; the increase in convexity increases its refractive power; the greater the degree of divergence of the rays previous to entering the eye, the greater the increase of convexity of the lens and convergence of the rays after passing through it. By this alteration in the shape of the lens we are enabled to focus light rays coming from, and to see distinctly, near as well as distant objects.

Function of the Ciliary Muscle.—Though it is admitted that the change in the convexity of the lens is caused by the contraction of the ciliary muscle and the relaxation of the suspensory ligament, the exact manner in which it does so is not understood. When the eye is in repose, as in distant vision, the suspensory ligament is tense and the lens possesses

that degree of curvature necessary for focusing parallel rays. In the voluntary efforts to accommodate the eye for near vision, the ciliary muscle contracts, the suspensory ligament relaxes, and the lens, inherently elastic, bulges forward and once again focuses the rays upon the retina. It is, therefore, termed the muscle of accommodation, and by its alternate contraction and relaxation the lens is rendered more or less convex, according to the requirements for near and distant vision.

Range of Accommodation.—Parallel rays coming from a luminous point, distant not less than 200 feet, do not require adjustment; from this point up to infinity no accommodation is required for perfect vision. This is termed the *punctum remotum*, and indicates the distance to which an object may be removed and yet distinctly seen. If the object be brought nearer to the eye than 200 feet, the accommodative power must come into play; the nearer the object the more energetic must be the contraction of the ciliary muscle and the consequent increase in the convexity of the lens. At a distance of five inches, however, the power of accommodation reaches its maximum; this is termed the *punctum proximum*, and indicates the nearest point at which an object may be seen distinctly. The distance between these two points is the range of accommodation.

Optical Defects.—*Astigmatism* is a condition of the eye which prevents vertical and horizontal lines from being focused at the same time, and is due to a greater curvature of the cornea in one meridian than another.

Spherical aberration is a condition in which there is an indistinctness of an image from the unequal refraction of the rays of light passing through the circumference and the center of the lens; it is corrected mainly by the iris, which cuts off the marginal rays, and only transmits those passing through the center.

Chromatic aberration is a condition in which the image is surrounded by a colored margin, from the decomposition of the rays of light into their elementary parts.

Myopia, or *shortsightedness*, is caused by an abnormal increase in the anteroposterior diameter of the eyeball, or by a hypernormal refracting power of the lens; it is generally due to the first cause; the lens, being too far removed from the retina, forms the image in front of it, and the perception becomes dim and blurred. *Concave* glasses correct this defect by preventing the rays from converging too soon.

Hypermetropia, or *longsightedness*, is caused by a shortening of the anteroposterior diameter or by a subnormal refractive power of the lens;

the focus of the rays of light would, therefore, be behind the retina. *Convex* glasses correct this defect by converging the rays of light more anteriorly.

Presbyopia is a loss of the power of accommodation of the eye to near objects, and usually occurs between the ages of forty and sixty; it is remedied by the use of convex glasses.

The Iris.—The iris plays the part of a diaphragm, and by means of its central aperture the pupil regulates the quantity of light entering the interior of the eye; by preventing rays from passing through the margin of the lens it diminishes spherical aberration. The size of the pupil depends upon the relative degree of contraction of the circular and radiating fibers; the variations in size of the pupil from variations in the degree of contraction depend upon different intensities of light. If the light be intense, the circular fibers contract and diminish the size of the pupil; if the light diminishes in intensity, the circular fibers relax and the pupil enlarges.

Point of Most Distinct Vision.—While all portions of the retina are sensitive to light, their sensibility varies within wide limits. At the macula lutea, and more especially in its most central depression, the fovea, where the retinal elements are reduced practically to the layer of rods and cones, the sensibility reaches its maximum. It is at this point that the image is found when vision is most distinct. The macula and fovea are always in the line of direct vision. From the macula toward the periphery of the retina there is a gradual diminution in sensibility and a corresponding decline in the distinctness of vision. In those portions of the retina lying outside the macula the indistinctness of vision depends not only on diminished sensibility, but also upon inaccurate focusing of the rays.

Blind Spot.—Although the optic nerve transmits the impulses excited in the retina by the ethereal vibration, the nerve fibers themselves are insensitive to light. At the point of entrance of the optic nerve, owing to the absence of the rods and cones, the rays of light make no impression. This is the blind spot. As this spot is not in the line of vision no dark point is ordinarily observed in the field of vision—that circular space before a fixed eye within which objects are perceptible.

The *rods* and *cones* are the most sensitive portions of the retina. A ray of light entering the eye passes entirely through the various layers of the retina and is arrested only upon reaching the pigmentary epithelium in which the rods and cones are imbedded. As to the manner in which the objective stimuli, light and color, so-called, are transformed into nerve impulses but little is known. It is probable that the ethereal vibrations are

transformed into heat, which excites the rods and cones. These, acting as highly specialized end organs of the optic nerve, start the impulses on their way to the brain, where the seeing process takes place. As to the relative function of the rods and cones, it has been suggested, from the study of the facts of comparative anatomy, that the rods are impressed only by differences in the intensity of light, while the cones in addition are impressed by qualitative differences or color.

Accessory Structures.—The muscles which move the eyeball are six in number: the superior and inferior recti, the external and internal recti, the superior and inferior oblique muscles. The four recti muscles, arising from the apex of the orbit, pass forward and are inserted into the sides of the sclerotic coat; the *superior* and *inferior* muscles rotate the eye around a *horizontal* axis; the *external* and *internal* rotate it around a *vertical* axis.

The *superior oblique* muscle, having the same origin, passes forward to the inner and upper angle of the orbital cavity, where its tendon passes through a cartilaginous pulley; it is then reflected backward and inserted into the sclerotic just behind the transverse diameter. Its *function* is to rotate the eyeball in such a manner as to direct the pupil *downward* and *outward*.

The *inferior oblique* muscle arises at the inner angle of the orbit and then passes outward and backward, to be inserted into the sclerotic. Its function is to rotate the eyeball and direct the pupil *upward* and *outward*.

By the associated action of all these muscles, the eyeball is capable of performing all the varied and complex movements necessary for distinct vision.

The *eyelids*, bordered with short, stiff hairs, shade the eye and protect it from injury. On the posterior surface, just beneath the conjunctiva, are the Meibomian glands, which secrete an oily fluid; it covers the edge of the lids, and prevents the tears from flowing over the cheek.

The *lacrimal glands* are ovoid in shape, and situated at the upper and outer part of the orbital cavity; they open by from six to eight ducts at the outer portion of the upper lids.

The *tears*, secreted by the lacrimal glands, are distributed over the cornea by the lids during the act of winking, and keep it moist and free from dust. The excess of tears passes into the lacrimal ducts, which begin by two minute orifices, one on each lid, at the inner canthus. They conduct the tears into the nasal duct, and so into the nose.

THE SENSE OF HEARING.

The Ear, or Organ of Hearing, is lodged within the petrous portion of the temporal bone. It may be, for convenience of description, divided into three portions, viz.:—

1. The external ear.
2. The middle ear.
3. The internal ear, or labyrinth.

The External Ear consists of the *pinna* or *auricle* and the *external auditory canal*. The *pinna* consists of a thin layer of cartilage, presenting a series of elevations and depressions; it is attached by fibrous tissue to the outer bony edge of the auditory canal; it is covered by a layer of integument continuous with that covering the side of the head. The general shape of the pinna is concave and presents a little below the center a deep depression, the *concha*. The *external auditory canal* extends from the concha inward for a distance of about 1½ inches. It is directed somewhat forward and upward, passing over a convexity of bone, and then dips downward to its termination; it is composed of both bone and cartilage, and lined by a reflection of the skin covering the pinna. At the external portion of the canal the skin contains a number of tubular glands, the *ceruminous glands*, which in their conformation resemble the perspiratory glands. They secrete the cerumen, or earwax.

The Middle Ear, or Tympanum, is an irregularly-shaped cavity hollowed out of the temporal bone and situated between the external ear and the labyrinth. It is narrow from side to side but relatively long in its vertical and anteroposterior diameters; it is separated from the external auditory canal by a membrane, the *membrana tympani*; from the internal ear it is separated by an osseomembranous partition which forms a common wall for both cavities. The middle ear communicates posteriorly with the mastoid cells, anteriorly with the nasopharynx by means of the Eustachian tube. The interior of this cavity is lined by mucous membrane continuous with that lining the pharynx.

The *membrana tympani* is a thin, translucent, nearly circular membrane, measuring about ⅜ of an inch in diameter, placed at the inner termination of the external auditory canal. The membrane is inclosed within a ring of bone which in the fetal condition can be easily removed, but in the adult condition becomes consolidated with the surrounding bone. The membrana tympani consists primarily of a layer of fibrous tissue, arranged both circularly and radially, and forms the *membrana propria*; externally

it is covered by a thin layer of skin continuous with that lining the auditory canal; internally it is covered by a thin mucous membrane. The tympanic membrane is placed obliquely at the bottom of the auditory canal, inclining at an angle of 45 degrees, being directed from behind and above downward and inward. On its external surface this membrane presents a funnel-shaped depression, the sides of which are somewhat convex.

The Ear Bones.—Running across the tympanic cavity and forming an irregular line of jointed levers is a chain of bones which articulate with

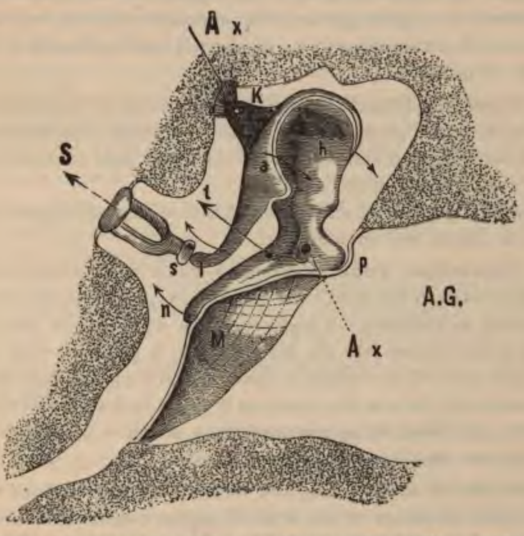

FIG. 29.—TYMPANUM AND AUDITORY OSSICLES (LEFT) MAGNIFIED.

A.G. External meatus. M. Membrana tympani, which is attached to the handle of the malleus, *n*, and near it the short process. *p*, *h*. Head of the malleus. *a*. Incus; *k*, its short process with its ligament; *l*, long process. *s*. Sylvian ossicle. S. Stapes. Ax, Ax, is the axis of rotation of the ossicles; it is shown in perspective, and must be imagined to penetrate the plane of the paper. *t*. Line of traction of the tensor tympani. The other arrows indicate the movement of the ossicles when the tensor contracts.

each other at their extremities. They are known as the malleus, incus, and stapes.

The form and position of these bones are shown in Fig. 29.

The *malleus* consists of a head, neck, and handle, of which the latter is attached to the inner surface of the membrana tympani; the *incus*, or anvil

bone, presents a concave, articular surface, which receives the head of the malleus; the *stapes*, or stirrup bone, articulates externally with the long process of the incus, and internally, by its oval base, with the edges of the foramen ovale.

The Tensor Tympani Muscle consists of a fleshy, tapering portion, half an inch in length, which terminates in a slender tendon; it arises from the cartilaginous portion of the Eustachian tube and adjacent surface of the sphenoid bone. From this origin the muscle passes nearly horizontally backward to the tympanic cavity; just opposite to the fenestra ovalis its tendon bends at a right angle over the processus cochleariformis and then passes outward across the cavity to be inserted into the handle of the malleus near the neck.

The Stapedius Muscle emerges from the cavity of a pyramid of bone projecting from the posterior wall of the tympanum; the tendon passes forward and is inserted into the neck of the stapes bone posteriorly near its point of articulation with the incus.

The laxator tympani muscle, so-called, is now generally regarded as ligamentous in nature, and not muscular.

The Eustachian Tube, by means of which a free communication is established between the middle ear and pharynx, is partly bony and partly cartilaginous in structure. It measures about 1½ inches in length; commencing at its opening into the naso-pharynx, it passes upward and outward to the spine of the sphenoid bone, at which point it becomes somewhat contracted; the tube then dilates as it passes backward into the middle ear cavity; it is lined by mucous membrane, which is continued into the middle ear and mastoid cells.

The Function of the Ear, as a whole, is the reception and transmission of aerial vibrations to the terminal organs concealed within the internal ear and which are connected with the auditory nerve fibers. The excitation of these end organs caused by the impact of the vibrations arouses in the auditory nerve impulses which are then transmitted to the brain, where the hearing process takes place. In order to appreciate the functions of the individual parts of the ear a few of the characteristics of sound waves must be kept in mind.

Sound Waves.—All sounds are caused by vibrations in the atmosphere which have been communicated to it by vibrating elastic bodies, such as membranes, strings, rods, etc. These vibrating bodies produce in the air a to-and-fro movement of its particles, resulting in a series of alternate condensations and rarefactions, which are propagated in all directions. A

complete oscillation of a particle of air forward and backward constitutes a sound-wave. Musical sounds are caused by a succession of regular waves, which follow each other with a certain rapidity. Noises are caused by the impact of a series of irregular waves.

All sound waves possess intensity, pitch, and quality. The *intensity*, or loudness, of a sound depends upon the amplitude of the vibrations or the extent of its excursion. The *pitch* depends upon the number of vibrations which affect the auditory nerve in a second of time; the pitch of the note C, the first below the leger line of the musical scale, is caused by 256 vibrations per second; the pitch of the same note an octave higher is caused by 512 vibrations per second. If the vibrations are too few per second they fail to be perceived as a continuous sound; the mininum number of vibrations capable of producing a sound has been fixed at 16 per second; the highest pitched musical note capable of being heard has been shown to be due to 38,000 vibrations per second. In the ascent of the musical scales there is, therefore, a gradual increase in the number of vibrations and a gradual increase in the pitch of the sounds. Between the two extreme limits lies the range of audibility, which embraces eleven octaves, of which seven are employed in the musical scale.

The *quality* of sound depends upon a combination of the fundamental vibration with certain secondary vibrations of subdivisions of the vibrating body. These so-called over-tones vary in intensity and pitch, and by modifying the form of the primary wave produce that which is termed the quality of sound.

Function of the Pinna and External Auditory Canal.—In those animals possessing movable ears, the pinna plays an important part in the collection of sound-waves. In man, in whom the capability of moving the pinna has been lost, it is doubtful if it is at all necessary for hearing. Nevertheless, an individual with dull hearing may have the perception of sound increased by placing the pinna at an angle of 45 degrees to the side of the head. The *external auditory canal* transmits the sonorous vibrations to the tympanic membrane. Owing to the obliquity of this canal it has been supposed that the waves, concentrated at the concha, undergo a series of reflections on their way to the tympanic membrane, and, owing to the position of this membrane, strike it almost perpendicularly.

Function of the Tympanic Membrane.—The function of the tympanic membrane appears to be the reception of sound vibrations by being thrown by them into reciprocal vibrations which correspond in intensity and amplitude. That this membrane actually reproduces all vibrations within

the range of audibility has been experimentally demonstrated. The membrane not being fixed, as far as its tension is concerned, does not possess a fixed fundamental note, like a stationary fixed membrane, and is therefore just as well adapted for the reception of one set of vibrations as another. This is made possible by variations in its tension in accordance with the pitch of the sounds. In the absence of all sound the membrane is in a condition of relaxation; with the advent of sound-waves possessing a gradual increase of pitch, as in the ascent of the musical scale, the tension of the tympanic membrane is gradually increased until its maximum tension is reached at the upper limit of the range of audibility. By this change in tension certain tones become perceptible and distinct, while others become indistinct and inaudible.

Function of the Tensor Tympani Muscle.—The function of this muscle is, as its name indicates, to increase the tension of the membrane in accordance with the pitch of the sound wave. The tendon of this muscle playing over the processus cochleariformis and attached at almost a right angle to the handle of the malleus will, when the muscle contracts, pull the handle inward, increase the convexity of the membrane, and at the same time increase its tension; with the relaxation of this muscle, the handle of the malleus passes outward and the tension is diminished. The contractions of the tensor muscle are reflex in character and excited by nerve impulses reaching it through the small petrosal nerve and otic ganglion. The number of nerve stimuli passing to the muscle and determining the degree of contraction will depend upon the pitch of the sound wave and the subsequent excitation of the auditory nerve. The tensor tympani muscle may be regarded as an accommodative apparatus by which the tympanic membrane is adjusted to enable it to receive vibrations of varying degrees of pitch.

Function of the Ossicles.—The function of the chain of bones is to transmit the sound wave across the tympanic cavity to the internal ear. The first of these bones, the malleus, being attached to the tympanic membrane, will take up the vibrations much more readily than if no membrane intervened. Owing to the character of the articulations, when the handle of the malleus is drawn inward, the position of the bones is so changed that they form practically a solid rod, and are therefore much better adapted for the transmission of molecular vibrations than if the articulations remained loose. As the stapes bone is somewhat shorter than the malleus, its vibrations are smaller than those of the tympanic membrane, and by this arrangement the amplitude of the vibrations is diminished, but their force *increased.*

The Function of the Stapedius Muscle is, according to Henle, to fix the stapes bone so as to prevent too great a movement from being communicated to it from the incus and transmitted to the perilymph. It may be looked upon, therefore, as a protective muscle.

The Function of the Eustachian Tube is to maintain a free communication between the cavity of the middle ear and naso-pharynx. The pressure of air within and without the ear is thus equalized, and the vibrations of the tympanic membrane permitted to attain their maximum, one of the conditions essential for the reception of sound waves. The impairment in the acuteness of hearing which is caused by an unequal pressure of the air in the middle ear can be shown :—

1. By closing the mouth and nose and forcing air from the lungs through the Eustachian tube into the ear, producing an increase in pressure.
2. By closing the nose and mouth, and making efforts at deglutition, which withdraws the air from the ear and diminishes its pressure. In both instances the free vibrations of the tympanic membrane are interfered with. The pharyngeal orifice of the Eustachian tube is opened by the action of certain of the muscles of deglutition, viz.: the levator palati, tensor palati, and the palato-pharyngei muscles.

The Internal Ear, or Labyrinth, is located in the petrous portion of the temporal bone, and consists of an osseous and membranous portion.

The Osseous Labyrinth is divisible into three parts, viz.: the vestibule, the semicircular canals, and the cochlea.

The *vestibule* is a small, triangular cavity, which communicates with the middle ear by the foramen ovale; in the natural condition it is closed by the base of the stapes bone. The filaments of the auditory nerve enter the vestibule through small foramina in the inner wall, at the fovea hemispherica.

The *semicircular canals* are three in number, the superior vertical, the inferior vertical, and the horizontal, each of which opens into the cavity of the vestibule by two openings, with the exception of the two vertical, which at one extremity open by a common orifice.

The *cochlea* forms the anterior part of the internal ear. It is a gradually tapering canal, about 1½ inches in length, which winds spirally around a central axis, the *modiolus*, 2½ times. The interior of the cochlea is partly divided into two passages by a thin plate of bone, the *lamina osseous spiralis*, which projects from the central axis ⅔ across the canal. These passages are termed the *scala vestibuli* and the *scala tympani*, from their communication with the vestibule and tympanum. The scala tympani

communicates with the middle ear through the *foramen rotundum*, which, in the natural condition, is closed by the 2d membrana tympani; superiorly they are united by an opening, the helicotrema.

The whole anterior of the labyrinth, the vestibule, the semicircular canals, and the scala of the cochlea, contains a clear, limpid fluid, the *perilymph*, secreted by the periosteum lining the osseous walls.

The Membranous Labyrinth corresponds to the osseous labyrinth with respect to form, though somewhat smaller in size.

The *vestibular* portion consists of two small sacs, the *utricle* and *saccule*.

The *semicircular canals* communicate with the *utricle* in the same manner as the bony canals communicate with the vestibule. The *saccule* communicates with the membranous cochlea by the canalis reuniens. In the interior of the utricle and saccule, at the entrance of the auditory nerve, are small masses of carbonate of lime crystals, constituting the *otoliths*. Their function is unknown.

The *membranous cochlea* is a closed tube, commencing by a blind extremity at the first turn of the cochlea, and terminating at its apex by a blind extremity also. It is situated between the edge of the *osseous lamina spiralis* and the outer wall of the bony cochlea, and follows it in its turns around the modiolus.

A transverse section of the cochlea shows that it is divided into two portions by the osseous lamina and the basilar membrane:—

1. The *scala vestibuli*, bounded by the periosteum and membrane of Reissner.
2. The *scala tympani*, occupying the inferior portion, and bounded above by the septum, composed of the osseous lamina and the membrana basilaris.

The *true membranous canal* is situated between the membrane of Reissner and the basilar membrane. It is triangular in shape, but is partly divided into a triangular portion and a quadrilateral portion by the *tectorial* membrane.

The *organ of Corti* is situated in the quadrilateral portion of the canal, and consists of pillars of rods of the consistence of cartilage. They are arranged in two rows—the one internal, the other external; these rods rest upon the basilar membrane; their bases are separated from each other, but their upper extremities are united, forming an arcade. In the internal row it is estimated there are about 3500, and in the external row about 5200 of these rods.

On the inner side of the internal row is a single layer of elongated hair

cells; on the outer surface of the external row are three such layers of hair cells. Nothing definite is known as to their function.

The *endolymph* occupies the interior of the utricle, saccule, and membranous canals, and bathes the structures in the interior of the membranous cochlea throughout its entire extent.

The Auditory Nerve at the bottom of the internal auditory meatus divides into—

1. A vestibular branch, which is distributed to the utricle and semicircular canals.
2. A cochlear branch, which passes into the central axis at its base and ascends to its apex; as it ascends, fibers are given off, which pass between the plates of the osseous lamina, to be ultimately connected with the organ of Corti.

The *function* of the semicircular canals appears to be to assist in maintaining the equilibrium of the body; destruction of the vertical canal is followed by an oscillation of the head upward and downward; destruction of the horizontal canal is followed by oscillations from left to right. When the canals are injured on both sides, the animal loses the power of maintaining equilibrium upon making muscular movements.

Function of the cochlea. It is regarded as possessing the power of appreciating the quality of pitch and the shades of different musical tones. The elements of the organ of Corti are analogous, in some respects, to a musical instrument, and are supposed, by Helmholtz, to be tuned so as to vibrate in unison with the different tones conveyed to the internal ear.

Summary.—The waves of sound are gathered together by the pinna and external auditory meatus, and conveyed to the membrana tympani. This membrane, made tense or lax by the action of the tensor tympani and laxator tympani muscles, is enabled to receive sound waves of either a high or low pitch. The vibrations are conducted across the middle ear by a chain of bones to the foramen ovale, and by the column of air of the tympanum to the foramen rotundum, which is closed by the 2d membrana tympani, the pressure of the air in the tympanum being regulated by the Eustachian tube.

The internal ear finally receives the vibrations, which excite vibrations successively in the perilymph, the walls of the membranous labyrinth, the endolymph, and, lastly, the terminal filaments of the auditory nerve, by which they are conveyed to the brain.

VOICE AND SPEECH.

The Larynx is the organ of voice. Speech is a modification of voice, and is produced by the teeth and the muscles of the lips and tongue, coordinated in their action by stimuli derived from the cerebrum.

The Structures entering into the formation of the larynx are mainly the *thyroid*, *cricoid*, and *arytenoid* cartilages; they are so situated and united by means of ligaments and muscles as to form a firm cartilaginous box. The larynx is covered externally by fibrous tissue, and lined internally with mucous membrane.

The Vocal Cords are four ligamentous bands, running antero-posteriorly across the upper portion of the larynx, and are divided into the *two superior* or *false* vocal cords, and the *two inferior* or *true* vocal cords; they are attached anteriorly to the receding angle of the thyroid cartilages and posteriorly to the anterior part of the base of the arytenoid cartilages. The space between the true vocal cords is the *rima glottidis*.

The Muscles which have a direct action upon the movements of the vocal cords are nine in number, and take their names from their points of origin and insertion, viz.: the two *crico-thyroid*, two *thyro-arytenoid*, two *posterior crico-arytenoid*, two *lateral crico-arytenoid*, and one *arytenoid* muscles.

The *crico-thyroid* muscles, by their contraction, render the vocal cords *more tense* by drawing down the anterior portion of the thyroid cartilage and approximating it to the cricoid, and at the same time tilting the posterior portion of the cricoid and arytenoid cartilages backward.

The *thyro-arytenoid*, by their contraction, *relax* the vocal cords by drawing the arytenoid cartilage forward and the thyroid backward.

The *posterior crico-arytenoid* muscles, by their contraction, rotate the arytenoid cartilages outward and thus separate the vocal cords and enlarge the aperture of the glottis. They principally aid the respiratory movements during inspiration.

The *lateral crico-arytenoid* muscles are antagonistic to the former, and by their contraction rotate the arytenoid cartilages so as to approximate the vocal cords and constrict the glottis.

The *arytenoid* muscle assists in the closure of the aperture of the glottis.

The *inferior laryngeal* nerve animates all the muscles of the larynx, with the exception of the crico-thyroid.

Movements of the Vocal Cords.—During respiration the movements of the vocal cords differ from those occurring during the production of voice.

At each *inspiration* the true vocal cords are widely separated, and the aperture of the glottis is enlarged by the action of the crico-arytenoid muscles, which rotate outward the anterior angle of the base of the arytenoid cartilages; at each *expiration* the larynx becomes passive; the elasticity of the vocal cords returns them to their original position, and the air is forced out by the elasticity of the lungs and the walls of the thorax.

Phonation.—As soon as phonation is about to be accomplished a marked change in the glottis is noticed with the aid of the laryngoscope. The true vocal cords suddenly become approximated and are made parallel, giving to the glottis the appearance of a narrow slit, the edges of which are capable of vibrating accurately and rapidly; at the same time their tension is much increased.

With the vocal cords thus prepared, the expiratory muscles force the column of air into the lungs and trachea through the glottis, throwing the edges of the cords into vibration.

The *pitch* of sounds depends upon the extent to which the vocal cords are made tense and the length of the aperture through which the air passes. In the production of sounds of a high pitch, the tension of the vocal cords becomes very marked and the glottis diminished in length. When grave sounds having a low pitch are emitted from the larynx, the vocal cords are less tense and their vibrations are large and loose.

The *quality* of voice depends upon the length, size, and thickness of the cords, and the size, form, and construction of the trachea, larynx, and the resonant cavities of the pharynx, nose, and mouth.

The *compass* of the voice comprehends from two to three octaves. The range is different in the two sexes, the lowest note of the male being about one octave lower than the lowest note of the female; while the highest note of the male is an octave less than the highest note of the female.

The *varieties* of voices, *e.g.*, bass, baritone, tenor, contralto, mezzo-soprano, and soprano, are due to the length of the vocal cords, being longer when the voice has a low pitch, and shorter when it has a high pitch.

Speech is the faculty of expressing ideas by means of combinations of sounds, in obedience to the dictates of the cerebrum.

Articulate sounds may be divided into *vowels* and *consonants*. The *vowel sounds*, *a*, *e*, *i*, *o*, *u*, are produced in the larynx by the vocal cords. The *consonant sounds* are produced in the air passages above the larynx by an interruption of the current of air by the lips, tongue, and teeth; the consonants may be divided into :—

1. Mutes, *b*, *d*, *k*, *p*, *t*, *c*, *g*.
2. Dentals, *d*, *j*, *s*, *t*, *z*.

3. Nasals, *m*, *n*, *ng*.
4. Labials, *b*, *p*, *f*, *v*, *m*.
5. Gutturals, *k*, *g*, *c*, and *g* hard.
6. Liquids, *l*, *m*, *n*, *r*.

REPRODUCTION.

Reproduction is the function by which the species is preserved, and accomplished by the organs of generation in the two sexes.

GENERATIVE ORGANS OF THE FEMALE.

The Generative Organs of the Female consist of the ovaries, Fallopian tubes, uterus, and vagina.

The Ovaries are two small, ovoid, flattened bodies, measuring 1½ inches in length and ¾ of an inch in width; they are situated in the cavity of the pelvis, and imbedded in the posterior layer of the broad ligament; attached to the uterus by a round ligament, and to the extremities of the Fallopian tubes by the fimbriæ. The ovary consists of an external membrane of fibrous tissue, the *cortical* portion, in which are imbedded the *Graafian vesicles*, and an internal portion, the *stroma*, containing blood-vessels.

The Graafian Vesicles are exceedingly numerous, but situated only in the cortical portion. Although the ovary contains the vesicles from the period of birth, it is only at the period of puberty that they attain their full development. From this time onward to the catamenial period there is a constant growth and maturation of the Graafian vesicles. They consist of an external investment, composed of fibrous tissue and blood-vessels, in the interior of which is a layer of cells forming the *membrana granulosa;* at its lower portion there is an accumulation of cells, the *proligerous disc*, in which the *ovum* is contained. The cavity of the vesicle contains a slightly yellowish, alkaline, albuminous fluid.

The Ovum is a globular body, measuring about the $\frac{1}{125}$ of an inch in diameter; it consists of an external investing membrane, the *vitelline membrane;* a central granular substance, the *vitellus*, or *yelk;* a nucleus, the *germinal vesicle*, in the interior of which is imbedded the nucleolus, or *germinal spot*.

The Fallopian Tubes are about four inches in length, and extend outward from the upper angles of the uterus, between the folds of the broad ligaments, and terminate in a fringed extremity which is attached by one of the fringes to the ovary. They consist of three coats:—

1. The external, or peritoneal.
2. Middle, or muscular, the fibers of which are arranged in a circular or longitudinal direction.
3. Internal, or mucous, covered with ciliated epithelial cells, which are always waving from the ovary toward the uterus.

The Uterus is pyriform in shape, and may be divided into a body and neck; it measures about three inches in length and two inches in breadth in the unimpregnated state. At the lower extremity of the neck is the os externum; at the junction of the neck with the body is a constriction, the os internum. The cavity of the uterus is triangular in shape, the walls of which are almost in contact.

The walls of the uterus are made up of several layers of non-striated muscular fibers, covered externally by peritoneum, and lined internally by mucous membrane, containing numerous tubular glands, and covered by ciliated epithelial cells.

The Vagina is a membranous canal, from five to six inches in length, situated between the rectum and bladder. It extends obliquely upward from the surface, almost to the brim of the pelvis, and embraces at its upper extremity the neck of the uterus.

Discharge of the Ovum.—As the Graafian vesicle matures, it increases in size, from an augmentation of its liquid contents, and approaches the surface of the ovary, where it forms a projection, measuring from ¼ to ½ an inch in size. The maturation of the vesicle occurs periodically, about every twenty-eight days, and is attended by the phenomena of menstruation. During this period of active congestion of the reproductive organs, the Graafian vesicle ruptures, the ovum and liquid contents escape, and are caught by the fimbriated extremity of the Fallopian tube, which has adapted itself to the posterior surface of the ovary. The passage of the ovum through the Fallopian tube into the uterus occupies from ten to fourteen days, and is accomplished by muscular contraction and the action of the ciliated epithelium.

Menstruation is a periodic discharge of blood from the mucous membrane of the uterus, due to a fatty degeneration of the small blood-vessels. Under the pressure of an increased amount of blood in the reproductive organs, attending the process of ovulation, the blood-vessels rupture, and a

hemorrhage takes place into the uterine cavity; thence it passes into the vagina. Menstruation lasts from five to six days, and the amount of blood discharged averages about five ounces.

Corpus Luteum.—For some time anterior to the rupture of a Graafian vesicle, it increases in size and becomes vascular; its walls become thickened from the deposition of a reddish-yellow, glutinous substance, a product of cell growth from the proper coat of the follicle and the membrana granulosa. After the ovum escapes, there is usually a small effusion of blood into the cavity of the follicle, which soon coagulates, loses its coloring matter, and acquires the characteristics of fibrin, but it takes no part in the formation of the corpus luteum. The walls of the follicle become convoluted, vascular, and undergo hypertrophy, until they occupy the whole of the follicular cavity. At its period of fullest development, the corpus luteum measures ¾ of an inch in length and ½ an inch in depth. In a few weeks the mass loses its red color and becomes yellow, constituting the *corpus luteum*, or *yellow body*. It then begins to retract and becomes pale; and at the end of two months nothing remains but a small cicatrix upon the surface of the ovary. Such are the changes in the follicle if the ovum has not been impregnated.

The corpus luteum, after impregnation has taken place, undergoes a much slower development, becomes larger, and continues during the entire period of gestation. The difference between the corpus luteum of the unimpregnated and pregnant condition is expressed in the following table by Dalton :—

	Corpus Luteum of Menstruation.	Corpus Luteum of Pregnancy.
At the end of three weeks.	Three-quarters of an inch in diameter; central clot reddish; convoluted wall pale.	
One month.	Smaller; convoluted wall bright yellow; clot still reddish.	Larger; convoluted wall bright yellow; clot still reddish.
Two months.	Reduced to the condi tion of an insignificant cicatrix.	Seven-eighths of an inch in diameter; convoluted wall bright yellow; clot perfectly decolorized.
Four months.	Absent or unnoticeable.	Seven-eighths of an inch in diameter; clot pale and fibrinous; convoluted wall dull yellow.
Six months.	Absent.	Still as large as at the end of second month; clot fibrinous; convoluted wall paler.
Nine months.	Absent.	Half an inch in diameter; central clot converted into a radiating cicatrix; external wall tolerably thick and convoluted, but without any bright yellow color.

GENERATIVE ORGANS OF THE MALE.

The Generative Organs of the Male consist of the testicles, vasa deferentia, vesiculæ seminales, and penis.

The Testicles, the essential organs of reproduction in the male, are two oblong glands, about 1½ inches in length, compressed from side to side, and situated in the cavity of the scrotum.

The proper coat of the testicle, the *tunica albuginea,* is a white, fibrous structure, about the $\frac{1}{25}$ of an inch in thickness; after enveloping the testicle, it is reflected into its interior at the posterior border, and forms a vertical process, the *mediastinum testes,* from which septa are given off, dividing the testicle in lobules.

The substance of the testicle is made up of the *seminiferous tubules,* which exist to the number of 840; they are exceedingly convoluted, and when unraveled are about 30 inches in length. As they pass toward the apices of the lobules, they become less convoluted, and terminate in from 20 to 30 straight ducts, the *vasa recta,* which pass upward through the *mediastinum* and constitute the *rete testis.* At the upper part of the mediastinum the tubules unite to form from 9 to 30 small ducts, the *vasa efferentia,* which become convoluted and form the *globus major* of the *epididymis;* the continuation of the tubes downward behind the testicle and a second convolution constitutes the *body* and *globus minor.*

The seminal tubule consists of a basement membrane lined by granular nucleated epithelium.

The Vas Deferens, the excretory duct of the testicle, is about two feet in length, and may be traced upward from the epididymis to the under surface of the base of the bladder, where it unites with the duct of the vesicula seminalis to form the ejaculatory duct.

The Vesiculæ Seminales are two lobulated, pyriform bodies, about two inches in length, situated on the inner surface of the bladder.

They have an external fibrous coat, a middle muscular coat, and an internal mucous coat, covered by epithelium, which secretes a mucous fluid. The vesiculæ seminales serve as reservoirs, in which the seminal fluid is temporarily stored up.

The Ejaculatory Duct, about ¾ of an inch in length, opens into the urethra, and is formed by the union of the vasa deferentia and the ducts of the vesiculæ seminales.

The Prostrate Gland surrounds the posterior extremity of the urethra, and opens into it by from 20 to 30 openings, the orifices of the *prostatic*

tubules. The gland secretes a fluid which forms part of the semen and assists in maintaining the vitality of the spermatozoa.

Semen is a complex fluid, made up of the secretions from the testicles, the vesicula seminales, the prostatic and urethral glands. It is grayish-white in color, mucilaginous in consistence, of a characteristic odor, and somewhat heavier than water. From half a dram to a dram is ejaculated at each orgasm.

The Spermatozoa are peculiar anatomical elements, developed within the seminal tubules, and possess the power of spontaneous movement. The spermatozoa consist of a conoidal head and a long, filamentous tail, which is in continuous and active motion; as long as they remain in the vas deferens they are quiescent, but when free to move in the fluid of the vesiculæ seminales become very active.

Origin.—The spermatozoa appear at the age of puberty, and are then constantly formed until an advanced age. They are developed from the nuclei of large, round cells contained in the anterior of the seminal tubules, as many as 15 to 20 developing in a single cell.

When the spermatozoa are introduced into the vagina, they pass readily into the uterus and through the Fallopian tubes toward the ovaries, where they remain and retain their vitality for a period of from eight to ten days.

Fecundation is the union of the spermatozoa with the ovum during its passage toward the uterus, and usually takes place in the Fallopian tube, just outside of the womb. After floating around the ovum in an active manner, they penetrate the vitelline membrane, pass into the interior of the vitellus, where they lose their vitality, and along with the germinal vesicle entirely disappear.

DEVELOPMENT OF ACCESSORY STRUCTURES.

Segmentation of the Vitellus.—After the disappearance of the spermatozoa and the germinal vesicle there remains a transparent, granular, albuminous substance, in the center of which a new nucleus soon appears; this constitutes the *parent cells*, and is the first stage in the development of the new being.

Following this, the vitellus undergoes *segmentation;* a constriction appears on the opposite side of the vitellus, which gradually deepens, until the yelk is divided into two segments, each of which has a distinct nucleus and nucleolus; these two segments undergo a further division into four, the four into eight, the eight into others, and so on, until the entire vitellus is

divided into a great number of cells, each of which contains a nucleus and nucleolus.

The peripheral cells of this "mulberry mass" then arrange themselves so as to form a membrane, and as they are subjected to mutual pressure, assume a polyhedral shape, which gives to the membrane a mosaic appearance. The central part of the vitellus becomes filled with a clear fluid. A secondary membrane shortly appears within the first, and the two together constitute the external and internal blastodermic membranes.

Germinal Area.—At about this period there is an accumulation of cells at a certain spot upon the surface of the blastodermic membranes which marks the position of the future embryo. This spot, at first circular, soon becomes elongated, and forms the *primitive trace*, around which is a clear space, the *area pellucida*, which is itself surrounded by a darker region, the *area opaca*.

The primitive trace soon disappears, and the area pellucida becomes guitar-shaped; a new groove, the *medullary groove*, is now formed, which develops from before backward, and becomes the neural canal.

Blastodermic Membranes.—The embryo, at this period, consists of three layers, viz.: the external and internal blastodermic membranes, and a middle membrane formed by a genesis of cells from their internal surfaces. These layers are known as the epiblast, mesoblast, and hypoblast.

The *epiblast* gives rise to the central nervous system, the epidermis of the skin and its appendages, and the primitive kidneys.

The *mesoblast* gives rise to the dermis, muscles, bones, nerves, blood-vessels, sympathetic nervous system, connective tissue, the urinary and reproductive apparatus, and the walls of the alimentary canal.

The *hypoblast* gives rise to the epithelial lining of the alimentary canal and its glandular appendages, the liver and pancreas, and the epithelium of the respiratory tract.

Dorsal Laminæ.—As development advances, the true medullary groove deepens, and there arise two longitudinal elevations of the epiblast, the *dorsal laminæ*, one on either side of the groove, which grow up, arch over, and unite so as to form a closed tube, the primitive central nervous system.

The Chorda Dorsalis is a cylindrical rod running almost throughout the entire length of the embryo. It is formed by an aggregation of mesoblastic cells, and situated immediately beneath the medullary groove.

Primitive Vertebræ.—On either side of the neural canal the cells of the mesoblast undergo a longitudinal thickening, which develops and ex-

tends around the neural canal and the chorda dorsalis, and forms the arches and bodies of the vertebræ. They become divided transversely into four-sided segments.

The *mesoblast* now separates into two layers; the external, joining with the epiblast, forms the *somatopleure;* the internal, joining with the hypoblast, forms the *splanchnopleure;* the space between them constituting the *pleuro-peritoneal* cavity.

Visceral Laminæ.—The walls of the pleuro-peritoneal cavity are formed by a downward prolongation of the somatopleure (the *visceral laminæ*), which, as they extend around in front, pinch off a portion of the yelk sac (formed by the splanchnopleure), which becomes the primitive alimentary canal; the lower portion, remaining outside of the body cavity, forms the *umbilical vesicle*, which after a time disappears.

Formation of Fetal Membranes.—The amnion appears shortly after the embryo begins to develop, and is formed by folds of the epiblast and external layer of the mesoblast, rising up in front and behind and on each side; these amniotic folds gradually extend over the back of the embryo to a certain point, where they coalesce and enclose a cavity, the amniotic cavity. The membranous partition between the folds disappears, and the outer layer recedes and becomes blended with the vitelline membrane, constituting the *chorion*, the external covering of the embryo.

The Allantois.—As the amnion develops, there grows out from the posterior portion of the alimentary canal a pouch, or diverticulum, the *allantois*, which carries blood-vessels derived from the intestinal circulation. As it gradually enlarges, it becomes more vascular, and inserts itself between the two layers of the amnion, coming into intimate contact with the external layer. Finally, from increased growth, it completely surrounds the embryo, and its edges become fused together.

In the bird, the allantois is a respiratory organ, absorbing oxygen and exhaling carbonic acid; it also absorbs nutritious matter from the interior of the egg.

Amniotic Fluid.—The amnion, when first formed, is in close contact with the surface of the ovum; but it soon enlarges, and becomes filled with a clear, transparent fluid, containing albumin, glucose, fatty matters, urea, and inorganic salts. It increases in amount up to the latter period of gestation, when it amounts to about two pints. In the space between the amnion and allantois is a gelatinous material, which is encroached upon and finally disappears as the amnion and allantois come in contact, at about the fifth month.

The Chorion, the external investment of the embryo, is formed by a fusion of the original vitelline membrane, the external layer of the amnion, and the allantois. The external surface now becomes covered with villous processes, which increase in number and size by the continual budding and growth of club-shaped processes from the main stem, and give to the chorion a shaggy appearance. They consist of a homogeneous granular matter, and are penetrated by branches of the blood-vessels derived from the aorta.

The presence of villous processes in the uterine cavity is proof positive of the previous existence of a fetus. They are characteristic of the chorion, and are found under no other circumstances.

At about the end of the second month the villosities begin to atrophy and disappear from the surface of the chorion, with the exception of those situated at the points of entrance of the fetal blood-vessels, which occupy about ⅓ of its surface, where they continue to grow longer, become more vascular, and ultimately assist in the formation of the placenta; the remaining ⅔ of the surface loses its villi and blood-vessels and becomes a simple membrane.

The Umbilical Cord connects the fetus with that portion of the chorion which forms the fetal side of the placenta. It is a process of the allantois, and contains two arteries and a vein, which have a more or less spiral direction. It appears at the end of the first month, and gradually increases in length, until, at the end of gestation, it measures about 20 inches. The cord is also surrounded by a process of the amnion.

Development of the Decidual Membrane.—The interior of the uterus is lined by a thin, delicate mucous membrane, in which are imbedded immense numbers of tubules, terminating in blind extremities, the *uterine tubules*. At each period of menstruation the mucous membrane becomes thickened and vascular, which condition, however, disappears after the usual menstrual discharge. When the ovum becomes fecundated, the mucous membrane takes on an increased growth, becomes more hypertrophied and vascular, sends up little processes or elevations from its surface, and constitutes the *decidua vera*.

As the ovum passes from the Fallopian tube into the interior of the uterus, the primitive vitelline membrane, covered with villosities, becomes entangled with the processes of the mucous membrane. A portion of the decidua vera then grows up on all sides and encloses the ovum, forming the decidua reflexa, while the villous processes of the chorion insert themselves into the uterine tubules and in the mucous membrane between them.

As development advances the decidua reflexa increases in size, and at about the end of the fourth month comes in contact with the decidua vera, with which it is ultimately fused.

The Placenta.—Of all the embryonic structures, the placenta is the most important. It is formed in the third month, and then increases in size until the seventh month, when a retrogressive metamorphosis takes place until its separation during labor, at which time it is of an oval or rounded shape, and measures from seven to nine inches in length, six to eight inches in breadth, and weighs from 15 to 20 ounces. It is most frequently situated at the upper and posterior part of the inner surface of the uterus.

The placenta consists of two portions, a fetal and a maternal.

The *fetal portion* is formed by the villi of the chorion, which, by developing, rapidly increase in size and number. They become branched and penetrate the uterine tubules, which enlarge and receive their many ramifications. The capillary blood-vessels in the anterior of the villi also enlarge and freely anastomose with each other.

The *maternal portion* is formed from that part of the hypertrophied and vascular decidual membrane between the ovum and the uterus, the *decidua serotina.* As the placenta increases in size, the maternal blood-vessels around the tubules become more and more numerous, and gradually fuse together, forming great lakes, which constitute sinuses in the walls of the uterus.

As the latter period of gestation approaches, the villi extend deeper into the decidua, while the sinuses in the maternal portion become larger and extend further into the chorion. Finally, from excessive development of the blood-vessels, the structures between them disappear, and as their walls come in contact, they fuse together, so that, ultimately, the maternal and fetal blood are only separated by a thin layer of a homogeneous substance. When fully formed, the placenta consists principally of blood-vessels interlacing in every direction. The blood of the mother passes from the uterine vessels into the lake surrounding the villi; the blood from the child flows from the umbilical arteries into the interior of the villi; but there is not at any time an intermingling of blood, the two being separated by a delicate membrane formed by a fusion of the walls of the blood-vessels and the walls of the villi and uterine sinuses.

The function of the placenta, besides nutrition, is that of a *respiratory organ*, permitting the oxygen of the maternal blood to pass by osmosis through the delicate placental membrane into the blood of the fetus; at the same time permitting the carbonic acid and other waste products, the result of nutritive changes in the fetus, to pass into the maternal blood, and so to be carried to the various eliminating organs.

Through the placenta also passes all the nutritious materials of the maternal blood which are essential for the development of the embryo.

At about the middle of gestation there develops beneath the decidual membrane a new mucous membrane, destined to perform the functions of the old when it is extruded from the womb, along with the other embryonic structures, during parturition.

DEVELOPMENT OF THE EMBRYO.

Nervous System.—The cerebro-spinal axis is formed within the medullary canal by the development of cells from its inner surfaces, which as they increase fill up the canal, and there remains only the central canal of the cord. The external surface gives rise to the dura mater and pia mater. The neural canal thus formed is a tubular membrane; it terminates posteriorly in an oval dilatation, and anteriorly in a bulbous extremity, which soon becomes partially contracted, and forms the anterior, middle, and posterior cerebral vesicles, from which are ultimately developed the cerebrum, the corpora quadrigemina, and medulla oblongata, respectively.

The *anterior vesicle* soon subdivides into two secondary vesicles, the larger of which becomes the hemispheres, the smaller the optic thalami; the *posterior vesicle* also divides into two, the anterior becoming the cerebellum, the posterior the pons Varolii and medulla oblongata.

About the seventh week the straight chain of cerebral vesicles becomes curved from behind forward and forms three prominent angles. As development advances, the relative size of the encephalic masses changes. The cerebrum, developing more rapidly than the posterior portion of the brain, soon grows backward and arches over the optic thalami and the tubercula quadrigemina; the cerebellum overlaps the medulla oblongata.

The surface of the cerebral hemispheres is at first smooth, but at about the fourth month begins to be marked by the future fissures and convolutions.

The Eye is formed by a little bud projecting from the side of the anterior vesicle. It is at first hollow, but becomes lined with nervous matter, forming the *optic nerve* and *retina;* the remainder of the cavity is occupied by the *vitreous body.* The anterior portion of the pouch becomes invaginated and receives the *crystalline lens,* which is a product of the epiblast, as is also the cornea. The *iris* appears as a circular membrane without a central aperture, about the seventh week; the eyelids are formed between the second and third months.

The Internal Ear is developed from the *auditory vesicle,* budding from

the 3d cerebral vesicle; the membranous vestibule appears first, and from it diverticula are given off, which become the semicircular canals and cochlea.

The cavity of the tympanum, the Eustachian tube, and the external auditory canal are the remains of the first branchial cleft, the cavity of this cleft being subdivided into the tympanum and external auditory meatus by the membrana tympani.

The Skeleton.—The chorda dorsalis, the primitive part of the vertebral column, is a cartilaginous rod situated beneath the medullary groove. It is a temporary structure, and disappears as the true bony vertebræ develop. On either side are the quadrate masses of the mesoblast, the primitive vertebræ, which send processes upward and around the medullary groove, and downward and around the chorda dorsalis, forming in these situations the arches and bodies of the future vertebræ.

More externally the outer layers of the mesoblast and epiblast arch downward and forward, forming the *ventral* laminæ, in which develop the *muscles* and *bones* of the abdominal walls.

The *true cranium* is an anterior development of the vertebral column, and consists of the occipital, parietal, and frontal segments, which correspond to the three cerebral vesicles. The *base of the cranium* consists, at this period, of a cartilaginous rod on either side of the anterior extremity of the chorda dorsalis, in which three centers of ossification appear, the *basi-occipital*, the *basisphenoidal*, and the *presphenoidal.* They ultimately develop into the basilar process of the occipital bone and the body of the sphenoid.

The *entire skeleton* is at first either membranous or cartilaginous. At the beginning of the second month centers of ossification appear in the jaws and clavicle; as development advances, the ossific points in all the future bones extend, until ossification is completed.

The *limbs* develop from four little buds projecting from the sides of the embryo, which, as they increase in length, separate into the thigh, leg, and foot, and the arm, forearm, and hand; the extremities of the limbs undergo subdivision, to form the fingers and toes.

Face and Visceral Arches.—In the facial and cervical regions the visceral laminæ send up three processes, the *visceral arches*, separated by clefts, the *visceral clefts.*

The *first*, or the *mandibular arches*, unite in the median line to form the lower jaw, and superiorly form the malleus. A process jutting from its base grows forward, unites with the frontonasal process growing from

above, and forms the upper jaw. When the superior maxillary processes fail to unite, there results the *cleft-palate* deformity; if the integument also fails to unite, there results the *hare-lip* deformity. The space above the mandibular arch becomes the mouth.

The *second arch* develops the incus and stapes bones, the styloid process and ligament, and the lesser cornua of the hyoid bone. The cleft between the first and second arches partially closes up, but there remains an opening at the side which becomes the Eustachian tube, tympanic cavity, and external auditory meatus.

The *third arch* develops the body and greater cornu of the hyoid bone.

Alimentary Canal and its Appendages.—The alimentary canal is formed by a pinching off of the yelk-sac by the visceral plates as they grow downward and forward. It consists of three distinct portions, the fore gut, the hind gut, and the central part, which communicates for some time with the yelk sac. It is at first a straight tube, closed at both extremities, lying just beneath the vertebral column. The canal gradually increases in length, and becomes more or less convoluted; at its anterior portion two pouches appear, which become the cardiac and pyloric extremities of the stomach. At about the seventh week the inferior extremity of the intestine is brought into communication with the exterior, by an opening, the anus. Anteriorly the mouth and pharynx are formed by an involution of epiblast, which deepens until it communicates with the fore gut.

The *liver* appears as a slight protrusion from the sides of the alimentary canal, about the end of the first month; it grows very rapidly, attains a large size, and almost fills up the abdominal cavity. The hepatic cells are derived from the intestinal epithelium, the vessels and connective tissue from the mesoblast.

The *pancreas* is formed by the hypoblastic membrane. It originates in two small ducts budding from the duodenum, which divide and subdivide, and develop the glandular structure.

The *lungs* are developed from the anterior part of the esophagus. At first a small bud appears, which, as it lengthens, divides into two branches; secondary and tertiary processes are given off these, which form the bronchial tubes and air cells. The lungs originally extended into the abdominal cavity, but became confined to the thorax by the development of the diaphragm.

The *bladder* is formed by a dilatation of that portion of the allantois remaining within the abdominal cavity. It is at first pear shaped, and communicates with the intestine, but later becomes separated, and opens

exteriorly by the urethra. It is attached to the abdominal walls by a rounded cord, the urachus, the remains of a portion of the allantois.

Genito-urinary Apparatus.—The *Wolffian bodies* appear about the thirteenth day, as long, hollow tubes running along each side of the primitive vertebral column. They are temporary structures, and are sometimes called the primordial kidneys. The Wolffian bodies consist of tubules which run transversely and are lined with epithelium; internally they become invaginated to receive tufts of blood-vessels; externally they open into a common excretory duct, the *duct* of the *Wolffian body*, which unites with the duct of the opposite body, and empties into the intestinal canal at a point opposite the allantois. On the outer side of the Wolffian body there appears another duct, the duct of Müller, which also opens into the intestine.

Behind the Wolffian bodies are developed the structures which become either the ovaries or testicles. In the development of the female the Wolffian bodies and their ducts disappear; the extremities of the Müllerian ducts dilate and form the fimbriated extremity of the Fallopian tubes, while the lower portions coalesce to form the body of the uterus and vagina, which now separate themselves from the intestine.

In the development of the male the Müllerian ducts atrophy, and the ducts of the Wolffian body ultimately form the epididymis and vas deferens. About the seventh month the testicles begin to descend, and by the ninth month have passed through the abdominal ring into the scrotum.

The *kidneys* are developed out of the Wolffian bodies. They consist of little pyramidal lobules, composed of tubules which open at the apex into the pelvis. As they pass outward they become convoluted and cup-shaped at their extremities, receive a tuft of blood-vessels, and form the Malpighian bodies.

The ureters are developed from the kidneys and pass downward to be connected with the bladder.

The Circulatory Apparatus assumes three different forms at different periods of life, all having reference to the manner in which the embryo receives nutritious matter and is freed of waste products.

The *vitelline circulation* appears first and absorbs nutritious material from the vitellus. It is formed by blood-vessels which emerge from the body and ramify over a portion of the vitelline membrane, constituting the *area vasculosa*. The heart, lying in the median line, gives off two arches which unite to form the abdominal aorta, from which two large arteries are given off, passing into the vascular area; the venous blood is returned

by veins which enter the heart. These vessels are known as the *omphalo-mesenteric arteries and veins.* The vitelline circulation is of short duration in the mammals, as the supply of nutritious matter in the vitellus soon becomes exhausted.

The *placental circulation* becomes established when the blood-vessels in the allantois enter the villous processes of the chorion and come into close relationship with the maternal blood-vessels. This circulation lasts during the whole of intra-uterine life, but gives way at birth to the adult circulation, the change being made possible by the development of the circulatory apparatus.

The *heart* appears as a mass of cells coming off from the anterior portion of the intestine; its central part liquefies, and pulsations soon begin. The heart is at first tubular, receiving posteriorly the venous trunks and giving off anteriorly the arterial trunks. It soon becomes twisted upon itself, so that the two extremities lie upon the same plane.

The heart now consists of a single auricle and a single ventricle. A septum, growing from the apex of the ventricle, divides it into two cavities, a right and a left. The auricles also become partly separated by a septum which is perforated by the foramen ovale. The arterial trunk becomes separated, by a partition, into two canals, which become, ultimately, the aorta and pulmonary artery. The auricles are separated from the ventricles by incomplete septa, through which the blood passes into the ventricles.

Arteries.—The aorta arises from the cephalic extremity of the heart and divides into two branches, which ascend, one on each side of the intestine, and unite posteriorly to form the main aorta; posteriorly to these first aortic arches four others are developed, so that there are five altogether running along the visceral arches. The two anterior soon disappear. The *third arch* becomes the internal carotid and the external carotid; a part of the *fourth arch*, on the right side, becomes the subclavian artery, and the remainder atrophies and disappears, but on the left side it enlarges and becomes the permanent aorta; the *fifth arch* becomes the pulmonary artery on the left side. The communication between the pulmonary artery and the aorta, the *ductus arteriosus*, disappears at an early period.

Veins.—The venous system appears first as two short, transverse veins, the canals of Cuvier, formed by the union of the vertebral veins and the cardinal veins, which empty into the auricle. The inferior vena cava is formed, as the kidneys develop, by the union of the renal veins, which, in a short time, receive branches from the lower extremities. The subclavian veins join the jugular as the upper extremities develop. The heart descends

in the thorax, and the canals of Cuvier become oblique; they shortly communicate by a transverse duct, which ultimately becomes the left innominate vein. The left canal of Cuvier atrophies and becomes a fibrous cord. A transverse branch now appears, which carries the blood from the left cardiac vein into the right, and becomes the vena azygos minor; the right cardiac vein becomes the vena azygos major.

Circulation of Blood in the Fetus.—The blood returning from the placenta, after having received oxygen and being freed from carbonic acid, is carried by the umbilical vein to the under surface of the liver; here a portion of it passes through the *ductus venosus* into the ascending vena cava, while the remainder flows through the liver and passes into the vena cava by the hepatic veins. When the blood is emptied into the right auricle it is directed by the Eustachian valve through the foramen ovale, into the left auricle, thence into the left ventricle, and so into the aorta to all parts of the system. The venous blood returning from the head and upper extremities is emptied, by the superior vena cava, into the right auricle, from which it passes into the right ventricle, and thence into the pulmonary artery. Owing to the condition of the lung only a small portion flows through the pulmonary capillaries, the greater part passing through the ductus arteriosus, which opens into the aorta at a point below the origin of the carotid and subclavian arteries. The mixed blood now passes down the aorta, to supply the lower extremities, but a portion of it is directed, by the hypogastric arteries, to the placenta, to be again oxygenated.

At birth, the placental circulation gives way to the circulation of the adult. As soon as the child begins to breathe, the lungs expand, blood flows freely through the pulmonary capillaries, and the ductus arteriosus begins to contract. The foramen ovale closes about the tenth day. The umbilical vein, the ductus venosus, and the hypogastric arteries become impervious in several days, and ultimately form rounded cords.

TABLE OF PHYSIOLOGICAL CONSTANTS.

Mean height of male, 5 feet 6½ inches; of female, 5 feet 2 inches.
Mean weight of male, 145 pounds; of female, 121 pounds.
Number of **chemic elements** in the human body: from 16 to 18.
Number of **proximate principles** in the human body: about 100.
Amount of **water** in the body weighing 145 pounds: 108 pounds.
Amount of **solids** in the body weighing 145 pounds: 36 pounds.
Amount of **saliva** secreted in 24 hours: about 3½ pounds.
  Function of **saliva**: converts starch into maltose.
  Active principle of **saliva**: **ptyalin.**
Amount of **gastric juice** secreted in 24 hours: from 8 to 14 pounds.
  Functions of **gastric juice**: converts albumin into peptone.
  Active principles of **gastric juice**: **pepsin and hydrochloric acid.**
Duration of **digestion**: from 3 to 5 hours.
Amount of **intestinal** juice secreted in 24 hours: about 1 pound.
  Function of **intestinal juice**: converts starch into maltose.
Amount of **pancreatic** juice secreted in 24 hours: about 1½ pounds.
  Active principles of pancreatic juice: **trypsin, amylopsin, and steapsin.**

Functions:
1. Emulsifies fats.
2. Converts albumin into peptone.
3. Converts starch into maltose.

Amount of bile poured into the intestines daily: about 2½ pounds.

Functions:
1. Assists in the emulsification of fats.
2. Stimulates the peristaltic movements.
3. Prevents putrefactive changes in the food.
4. Promotes the absorption of the fat.

Amount of **blood** in the body: from 16 to 18 pounds.
Size of **red corpuscles**: $\frac{1}{3200}$ of an inch.
Size of **white corpuscles**: $\frac{1}{2500}$ of an inch.
Shape of **red corpuscles**: circular biconcave discs.
Shape of **white corpuscles**: globular.
Number of **red corpuscles** in a cubic millimeter of blood (the cubic $\frac{1}{25}$ of an inch): 5,000,000.

Function of **red corpuscles**: to carry oxygen from the lungs to the tissues.

Frequency of the **heart's pulsation** per minute: 72 on the average.

Velocity of the **blood movement** in the arteries: about 12 inches per second.

Length of time required for the **blood** to make an entire circuit of the vascular system: about 20 seconds.

Amount of **air** passing in and out of the lungs at each respiratory act: from 20 to 30 cubic inches.

Amount of **air** that can be taken into the lungs on a forced inspiration: 110 cubic inches.

Amount of **reserve air** in the lungs after an ordinary expiration: 100 cubic inches.

Amount of **residual air** always remaining in the lungs: about 100 cubic inches.

Vital capacity of the **lungs**: 230 cubic inches.

Entire volume of **air** passing in and out of the lungs in 24 hours: about 400 cubic feet.

Composition of the **air**: nitrogen, 79.19; oxygen, 20.81, per 100 parts.

Amount of **oxygen** absorbed in 24 hours: 18 cubic feet.

Amount of **carbonic acid** exhaled in 24 hours: 14 cubic feet.

Temperature of the **human body** at the surface: $98\frac{6}{10}°$ F.

Amount of **urine** excreted daily: from 40 to 50 ounces.

Amount of **urea** excreted daily: 512 grains.

Specific gravity of **urine**: from 1.015 to 1.025.

Number of **spinal nerves**: 31 pairs.

Number of **roots of origin**: two; 1st, anterior, efferent; 2d, posterior, afferent.

Rate of transmission of **nerve force**: about 100 feet per second.

Number of **cranial nerves**: 12 pairs.

Nerves of special sense:

1. Olfactory, or 1st pair.
2. Optic, or 2d pair.
3. Auditory, or 8th pair.
4. Chorda tympani for anterior $\frac{2}{3}$ of tongue.
5. Branches of glosso-pharyngeal, or 8th pair, for posterior $\frac{1}{3}$ of tongue.

Motor nerves to **eyeball** and **accessory structures**: motor oculi, or 3d pair; pathetic, or 4th pair; abducens, or 6th pair.

Motor nerves to **facial muscles**: portio dura, facial, or 7th pair.

Motor nerve to **tongue**: hypoglossal, or 12th pair.

Motor nerve to **laryngeal muscles**: spinal accessory, or 11th pair.

Sensory nerve of the **face**: trifacial, or 5th pair.

Sensory nerve of the **pharynx**: glosso-pharyngeal, or 9th pair.

Sensory nerves of the **lungs, stomach, etc.**: pneumogastric, or 10th pair.

Length of **spinal cord**: 16 to 18 inches; weight $1\frac{1}{2}$ ounces.

Point of decussation of **motor fibers**: at the medulla oblongata.

Point of decussation of **sensory fibers**: throughout the spinal cord.

Function of **antero-lateral columns of spinal cord**: transmit motor impulses from the brain to the muscles.

Functions of the **posterior columns**: assist in the coordination of muscular movements.

Functions of the **medulla oblongata**: controls the functions of insalivation, mastication, deglutition, respiration, circulation, etc.

Functions of the **corpora quadrigemina**: physical centers for sight.

Functions of the **corpora striata**: centers for motion.

Functions of the **optic thalami**: centers for sensation.

Function of the **cerebellum**: center for the coordination of muscular movement.

Function of the **cerebrum**: center for intelligence, reason, and will.

Center for **articulate language**: 3d frontal convolution on the left side of cerebrum.

Number of coats to the **eye**: three; 1st, cornea and sclerotic; 2d, choroid; 3d, retina.

Function of **iris**: regulates the amount of light entering the eye.

Function of **crystalline lens**: refracts the rays of light so as to form an image on the retina.

Function of **retina**: receives the impressions of light.

Function of **membrana tympani**: receives and transmits waves of sound to internal ear.

Function of **Eustachian tube**: regulates the passage of air into and from the middle ear.

Function of **semicircular canals**: assist in maintaining the equipoise of the body.

Function of the **cochlea**: appreciates the shades and combinations of musical tones.

Size of **human ovum**: $\frac{1}{125}$ of an inch in diameter.

Size of **spermatozoa**: $\frac{1}{4000}$ of an inch in length.

Function of the **placenta**: acts as a respiratory and digestive organ for the fetus.

Duration of **pregnancy**: 280 days.

TABLE SHOWING RELATION OF WEIGHTS AND MEASURES OF THE METRIC SYSTEM TO APPROXIMATE WEIGHTS AND MEASURES OF THE U. S.

MEASURES OF LENGTH.

One Myriameter	=	10,000 meters	= 32800.	feet.
One Kilometer	=	1,000 "	= 3280.	"
One Hectometer	=	100 "	= 328.0	"
One Decameter	=	10 "	= 32.80	"
One METER	=	the ten millionth part of a quarter of the Meridian of the Earth	= 39.368	inches.
One Decimeter	=	the tenth part of one meter	= 3.936	"
One Centimeter	=	the one hundredth part of one meter.	= .393 ($\frac{2}{5}$)	"
One Millimeter	=	the one thousandth part of one meter	= .039 ($\frac{1}{25}$)	"

WEIGHTS.

One Myriagram	=	10,000 grams	= 26¾ pounds	Troy.
One Kilogram	=	1,000 "	= 2⅔ "	"
One Hectogram	=	100 "	= 3¼ ounces	"
One Decagram	=	10 "	= 2½ drams	"
One GRAM	=	the weight of a cubic centimeter of water at 4° C.	= 15.434	grains.
One Decigram	=	the tenth part of a gram	= 1.543 (1½)	"
One Centigram	=	the hundredth part of one gram	= .154 (⅙)	"
One Milligram	=	the thousandth part of one gram	= .015 ($\frac{1}{64}$)	"

MEASURES OF CAPACITY.

One Myrialiter	=	10 cubic Meters or the measure of 10 Milliers of water	= 2600.	gallons.
One Kiloliter	=	1 cubic Meter or the measure of 1 Millier of water.	= 260.	"
One Hectoliter	=	100 cubic Decimeters or the measure of 1 Quintal of water	= 26.	"
One Decaliter	=	10 cubic Decimeters or the measure of 1 Myriagram of water	= 2.6	"
One LITER	=	1 cubic Decimeter or the measure of 1 Kilogram of water	= 2.1	pints.
One Deciliter	=	100 cubic Centimeters or the measure of 1 Hectogram of water	= 3.3	ounces.
One Centiliter	=	10 cubic Centimeters or the measure of 1 Decagram of water	= 2.7	drams.
One Milliliter	=	1 cubic Centimeter or the measure of 1 Gram of water.	= 16.2	minims.

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